

THIS REPORT HAS BEEN DELIMITED
AND CLEARED FOR PUBLIC RELEASE
UNDER DOD DIRECTIVE 5200.20 AND
NO RESTRICTIONS ARE IMPOSED UPON
ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE,
DISTRIBUTION UNLIMITED.

UNCLASSIFIED

309 984

AD

CLASSIFICATION CHANGED
TO: UNCLASSIFIED
FROM: CONFIDENTIAL
AUTHORITY:

— USNSWC notice, 20 Oct 76 —
— cu —

UNCLASSIFIED

"NOTICE: When Government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the U.S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto."

CONFIDENTIAL

1
FC

NAVAL PROVING GROUND
DAHLGREN, VIRGINIA



REPORT NO. 6-44



AD No. 309984
ASTIA FILE COPY

**A METALLURGICAL INVESTIGATION OF THE
UNIFORMITY OF 3" CLASS "A" ARMOR PLATES**

"This document contains information affecting the National
Defense of the United States within the meaning of the
Espionage Laws, Title 18, U. S. C., Section 793 and
794. Its transmission or the revelation of its contents
in any manner to an unauthorized person is prohibited
by law."

FILE COPY

Return to

**ASTIA
ARLINGTON HALL STATION
ARLINGTON 12, VIRGINIA**

ATTN: YISSS

4 March 1944.

6-44
C.26

35 ALL COI

NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

4 March 1944

REPORT NO. 6 -44

A METALLURGICAL INVESTIGATION OF THE
UNIFORMITY OF 3" CLASS "A" ARMOR PLATE.

APPROVED

David I. Hedrick
DAVID I. HEDRICK,
CAPTAIN, U.S. NAVY,
COMMANDING OFFICER.

PREFACE

AUTHORIZATION

This study has been conducted under Naval Proving Ground Experimental Project APL-5 as authorized in Bureau of Ordnance letter NP9/A9(Re3) dated 9 January, 1943.

OBJECT

To determine the metallurgical characteristics of 3" Class A armor plates and to correlate these characteristics with ballistic performance.

SUMMARY

Ballistic limit determinations were made on eight 3" Class A ballistic test plates with 3" AP M61 projectiles at 20° obliquity. The plates were sectioned for metallurgical investigation including chemical composition, tensile properties, hardness distribution, macroexamination and microexamination.

A variation in ballistic quality was found to exist both between different plates and over the area of a single plate. The maximum difference in ballistic limit was 15% against 3" AP M61 projectiles.

An excellent correlation was obtained between ballistic limit and hardness distribution. It is shown that plates with high surface hardness and hard, deep chills have high limits against the 3" AP M61 projectiles.

CONTENTS

	<u>Page</u>
I INTRODUCTION	1
II BALLISTIC TESTS	1
III METALLURGICAL STUDY	2
IV DISCUSSION	3
V CONCLUSIONS	5
VI APPENDIX:	
A - BALLISTIC RESULTS.	7
B - PHOTOGRAPHS OF BALLISTIC TEST PLATES.	11
C - HARDNESS DISTRIBUTION CURVES THROUGH PLATE CROSS SECTIONS.	12
D - MACROETCHED CROSS SECTIONS OF PLATES.	13
E - REPRESENTATIVE PHOTOMICROGRAPHS OF FACE AND BACK OF PLATES.	14
F - CHEMICAL COMPOSITION, TENSILE PROPERTIES OF BACK AND CHILL TEST RESULTS.	15
G - SKETCHES OF MANUFACTURERS' PLATES SECTIONED FOR SMALL TEST PLATES.	20

LIST OF FIGURES

- Fig. 1-8 Front Views of Ballistic Test Plates (3" Class "A" vs. 3" Mol Projectiles) APL Nos. 278, 209, 275, 290, 279, 289, 280, 288.
APPENDIX B.
- Fig. 9-13 Hardness Distribution Curves Through Cross Sections of 3" Class "A" Plates APL Nos. 278, 209, 275, 290, 279, 289, 280, 288.
APPENDIX C.
- Fig. 14-18 Macroetched Cross Sections of 3" Class "A" Plates APL Nos. 278, 209, 275, 290, 279, 289, 280, 288.
APPENDIX D.
- Fig. 19-23 Representative Microstructures of Face and Back of 3" Class "A" Plates APL Nos. 278, 209, 275, 290, 279, 289, 280, 288.
APPENDIX E.
- Fig. 24-28 Sketches of Manufacturers Plates Sectioned for Small Test Plates: Midvale 7226-2, Carnegie EE630, JJ256, JJ298, JJ654.
APPENDIX G.

I. INTRODUCTION.

For the past two years an increasing amount of work has been done on testing various 3" AP Projectiles against 3" Class "A" armor plate. Little information has been available concerning the metallurgical characteristics or the uniformity of these test plates. With this in view it was considered desirable to study several 3" Class "A" armor plates as to chemical composition, hardness distribution, depth of chill, depth of "hard" face, tensile properties, macrostructure and microstructure.

Plates were supplied as 12' by 9' Projectile Test Plates for acceptance test at the Plate Battery of the Naval Proving Ground. They were subsequently sectioned into plates 3' by 3' for tests at the Armor and Projectile Laboratory Range where the firing reported herein was carried out.

II BALLISTIC TESTS.

Test Conditions:

Gun: 3"/50 Cal. Mk. 19 No. 5523.
Projectiles: 3" M61 AP projectiles manufactured by Bethlehem Steel Co. (Beth. Dwg. No. DA-301).
Obliquity: 20°

The results of ballistic tests, which are given in detail in Appendix A, are summarized below. Penetration and effective limits are expressed as per cent of theoretical Class B plate limits given in Buord Sk. 78841.

<u>APL Plate No.</u>	<u>Mfg.</u>	<u>Mfg. Plate No.</u>	<u>Penetration Limit</u>		<u>Effective Limit</u>
278	Midvale	7226-2	105±1		105±1
209	Carn.-Ill.	EE630	107±1		107±1
275	Carn.-Ill.	JJ256	118±2	above	126
290	Carn.-Ill.	JJ256	116±2		120±2
279	Carn.-Ill.	JJ298	118±2		118±2
289	Carn.-Ill.	JJ298	112±2		112±2
280	Carn.-Ill.	JJ654	120±2	above	125
288	Carn.-Ill.	JJ654	115±2		117±1

The plate quality is specified in terms of two limits. The "penetration limit" is the minimum velocity at which all of the projectile penetrates the plate regardless of the condition of the projectile. The "effective limit" is the minimum velocity at which a complete penetration is obtained with the projectile in an effective bursting condition.

Photographs of the ballistic test plates and projectiles are included in Appendix B.

III METALLURGICAL STUDY.

HARDNESS DISTRIBUTIONS.

Appendix C contains hardness distribution curves for each of the plates tested. These show the variation of "R_C" hardness through the cross section from face to back.

The "chill" depth has been taken as the distance from the face to a point where the hardness distribution curve falls to a value of R_C - 35. Similarly the "hard face" depth, related to the manufacturers' "undrillable" depth, is the distance from the face to a hardness of R_C - 50 on the curve. These are more or less arbitrary selections of hardness, but experience has shown that the limits of the chill and the undrillable depths as determined by the manufacturers' drill tests are generally located at approximately these values.

MACROEXAMINATION.

Two cross-section samples of each plate were given different Macro-etches; the first, an ammonium persulphate etch to delineate the depth of carburization, the depth of chill and the flow lines in the metal; and the second, a hot-acid deep etch to show up any macro-segregation as well as flow lines. Photographs of these etched sections given in Appendix D show normal segregation and wavy flow lines indicating the difficulty of uniform forging on this gauge of armor. The depth of chill can be measured from the persulphate etched sections as a check on the results obtained by hardness measurements.

MICROEXAMINATION.

Photomicrographs are given in Appendix E which are representative of the microstructures of each plate. In all cases, the face consists of many undissolved carbides in a martensitic matrix. while the back shows a normal fine spheroidized structure with ferrite matrix.

CHEMICAL AND PHYSICAL PROPERTIES.

Chemical analyses were made on all plates as checks against the manufacturer's reported composition. Detailed results given in Appendix F show only minor differences between A. & P. Laboratory and reported analyses. The physical properties were obtained on each plate and reported in Appendix F. The results check quite closely the values given by the manufacturer.

The per cent "chill" and per cent "hard face" determined from the hardness distribution curves are included in Appendix F together with the chill and undrillable depths as determined by the manufacturer's drill test. It will be noted that in a single full size plate there is as much as 10% variation in per cent chill and 7% variation in per cent undrillable.

Appendix G contains schematic drawings of the manufacturer's plates showing method of sectioning for the small test plates. The positions from which metallurgical samples were taken are shown by cross hatched areas.

IV DISCUSSION.

All but one of the 3" Class A plates studied in this report were made by Carnegie-Illinois. They are all similar in chemical composition and have similar tensile properties and yet there is a maximum difference of 15% in "penetration" limit and of over 20% in "effective" limit against the 3" AP M61 projectile at 20° obliquity. This difference can be correlated directly with the hardness distribution introduced by the final water hardening heat treatment.

In the table below the plates are listed in the order of their "penetration" limit velocities. The per cent "chill", per cent "hard" face and maximum face hardness were obtained from the hardness distribution

curves shown in Appendix C. These curves are considered to be representative of the 3' x 3' plates from which the samples were taken.

APL PLATE NO.	Mfg. Plate No.	Penetration Limit Vel. (% Sk.78841)	% Chill Depth ("R _C "-35)	% Hard Depth (R _C -50)	Max.Face Hardness ("R _C ")
Group A					
278	7226-2	105±2	33	9	53
209	EE630	107±2	32	12	52
289	JJ298	112±2	32	11	57
Group B					
288	JJ654	115±2	45	19	57.5
290	JJ256	116±2	34	17	58
275	JJ256	118±2	44	18	59
279	JJ298	118±2	41	18	58.5
280	JJ654	120±2	50	18	58

For ease in comparing the plates, they have been divided into two groups (A)-plates with low limit velocities, and (B)-plates with high limit velocities. In Group A, the plates have shallow chill (32% to 33%) and little "hard" face (9% to 12%). In Group B, the plates have varying depth of chill (34% to 50%), but all have a high percentage of "hard" face (17% to 19%) and all have a high face hardness (R_C 57 to R_C 59).

It is difficult to determine the relative importance of per cent chill depth, per cent "hard" depth, and maximum hardness because, in general, the deeper the chill, the higher the maximum hardness and the greater the per cent "hard" depth. However, from the results obtained on these eight plates the following generalities can be drawn.

Per Cent Chill does not appear to be a controlling factor. In Group E, the per cent chill varies 16%, while variation in limit is only 5%. Plate APL 290 with 34% chill has an 11% margin over plate APL 278 with 33% chill. On the other hand plate APL 290 has approximately the same limit as plate APL 288 which has a 45% chill.

Per Cent "Hard" is a very important factor and a high percentage of "hard" face is essential to obtain high ballistic limits. This is confirmed by these data and by the experience of the Naval Proving Ground on other gauges of Class A armor.

Maximum Face Hardness is important as shown by the results on plates APL 209 and APL 289. These plates have approximately the same per cent chill and per cent "hard" and have a 5% difference in limit. This difference can be ascribed to the higher face hardness of Plate APL 289. In all probability there is a critical hardness, dependent on the projectile hardness, to which the plate face must be raised in order for the plate to have a high ballistic limit. If the maximum face hardness is below this critical hardness, the plate will have a low limit. On the other hand, it is believed that variations in face hardness will not have marked effects on plate limits as long as the face is sufficiently hard to break up the projectile. The hardness of the cap and of the nose of 3" projectiles is approximately R_C 55 while the majority of 3" Class A plates obtained recently have a face hardness of about R_C 58.

V CONCLUSIONS:

The ballistic tests on 3" Class A plates against 3" AP M61 projectiles show a wide variation in limit between plates and between different areas in the same plate. The maximum variation in penetration limits in the eight plates investigated is 15% with a 6% variation in plates taken from a single large plate. The variation in "effective" limit, that is, in the minimum velocity at which a complete penetration is obtained with the projectile in an effective bursting condition, is over 21% between plates and over 8% in a single large plate.

The plates are quite similar in chemical composition, tensile properties and microstructure. The main variation in the plates is in the hardness distribution introduced during final water hardening. An excellent correlation can be obtained between the ballistic properties of the plate and the hardness distribution. A high per cent of "hard" face is required to obtain high limits.

The maximum face hardness is another important factor in obtaining high ballistic quality. A hardness

of at least RC 57 is required against 3" AP M61 projectiles.

The per cent chill is found to be relatively unimportant in determining ballistic quality. Wide variations in chill have little effect on the limits of the plates as long as the per cent "hard" and maximum face hardness are the same.

APPENDIX A

BALLISTIC RESULTS

SYMBOLS

"e" . . . . .	.Plate thickness at impact in inches.
"θ" . . . . .	.Obliquity.
S.V.,f.s . . . . .	.Striking velocity, feet per second.
Pene. . . . .	.Depth of penetration in inches.
Comp. . . . .	.Complete Penetration. Projectile completely through the plate.
Inc. . . . .	.Incomplete Penetration. Projectile rejected.
SIP . . . . .	.Projectile stuck in Plate.
Partial . . . . .	.Part of projectile through plate.
% . . . . .	.% empirical $F(e/d, \theta)$ value (Buord Sk. 78841).
F-. . . . .	.Thompson F-coefficient defined by the relation:

$$F = \frac{41.57 M^{1/2} V_L \cos \theta}{e^{1/2} d}$$

where V_L = limit velocity (minimum velocity for complete penetration)

BALLISTIC DATA

Projectile: 3" M 61 AP Projectiles manufactured by Bethlehem Steel Company (Beth. Dwg. No. DA-301) at 20° obliquity.

Plate: 3" Class "A" as cited.

Midvale No. 7226-2

<u>B.I.No.</u>	<u>APL Plate No.</u>	<u>"e"</u>	<u>"θ"</u>	<u>S.V. f.s</u>	<u>Pene.</u>	<u>Proj.Cond.</u>	<u>% Sk. 78841</u>
1737 APL	278	3"20	20°10'	1777	Inc.	Eff.Base dent. Nose intact.	103
1738 APL	278	3"20	20°20'	1807	1-3/4"	Ineff. Shat- tered.	104
1739 APL	278	3"20	20°10'	1834	Comp.	Eff. Base dent. Nose intact.	106
1736 APL	278	3"20	19°30'	1857	Comp.	Eff. Base dent. Nose intact.	108

Beth. M61 (Group D) Est.Limit F = 51,500±400(105±1%)

Carnegie-Illinois No. EE-630

1211 APL	209	3"22	19°45'	1771	Inc.	Ineff.Shattered	99
1212 APL		3"21	19°25'	1874	Inc.	Ineff.Shattered	106
1210 APL		3"23	20°10'	1924	Comp.	Eff.Whole	108
1209 APL		3"18	20°20'	2045	Comp.	Eff.Whole	116

Beth. M61 (Group D)Limit-F = 52,300±500(107±1%)

Carnegie-Illinois No. JJ256

1766 APL	275	3"21	19°40'	2014	Inc.	Ineff.Shattered	116
1767 APL		3"21	19°40'	2087	Comp.	Ineff. Nose broken	121
1768 APL		3"21	19°30'	2169	Comp.	Ineff. Split into cavity.	126

Beth. M61 (Group D)Limit-F =58,000±1000(118±2%)

1805 APL	290	3"42	20°00'	1998	Inc.	Ineff. Shat- tered.	109
1802 APL		3"42	20°10'	2038	Par.	Ineff. Nose shattered.	114
1803 APL		3"42	20°00'	2157	Comp.	Ineff.Nose off	118
1804 APL		3"42	19°50'	2177	Comp.	Eff.Nose off.	119
1805 APL		3"42	20°00'	2226	Comp.	Prob. Ineff. Nose off.	122

Beth. M61 (Group D)Limit F = 58,000±100(116±2%)

Carnegie - Illinois No. JJ298

<u>B.I.No.</u>	<u>APL Plate No.</u>	<u>"e"</u>	<u>"θ"</u>	<u>S.V. f.s.</u>	<u>Pene.</u>	<u>Proj.Cond.</u>	<u>% Sk. 78841</u>
1740	APL 279	3"15	20°00'	1887	Inc.	Ineff. Shat- tered.	111
1742	APL	3"15	20°00'	1983	SIP	Ineff. Nose split into cavity.	116
1741	APL	3"15	20°00'	2050	Comp.	Eff. Intact	120

Beth. M61 (Group D) Limit F = 57,000±1000(118±2%)
(Effective Penetration at 120%)

1801	APL 289	3"18	20°30'	1886	Inc.	Ineff. Shat- tered.	109
1800	APL	3"18	20°00'	1953	Comp.	Effective. Whole.	114
1799	APL	3"18	20°10'	1993	Comp.	Effective. Whole	116

Beth. M61 (Group D) Limit -F = 54,500±1000 1(112±2%)

Carnegie-Illinois No. JJ654

1769	APL 280	3"12	19°30'	1963	Par.	Ineff. Shat- tered.	116
1770	APL	3"11	19°50'	2032	CP	Not recovered	120
1771	APL	3"13	19°40'	2023	Par.	Ineff. Shat- tered.	120
1772	APL	3"12	19°30'	2113	Comp.	Ineff. Shat- tered.	125

Beth. M61 (Group D) Limit F = 58,200±1000(120±2%)

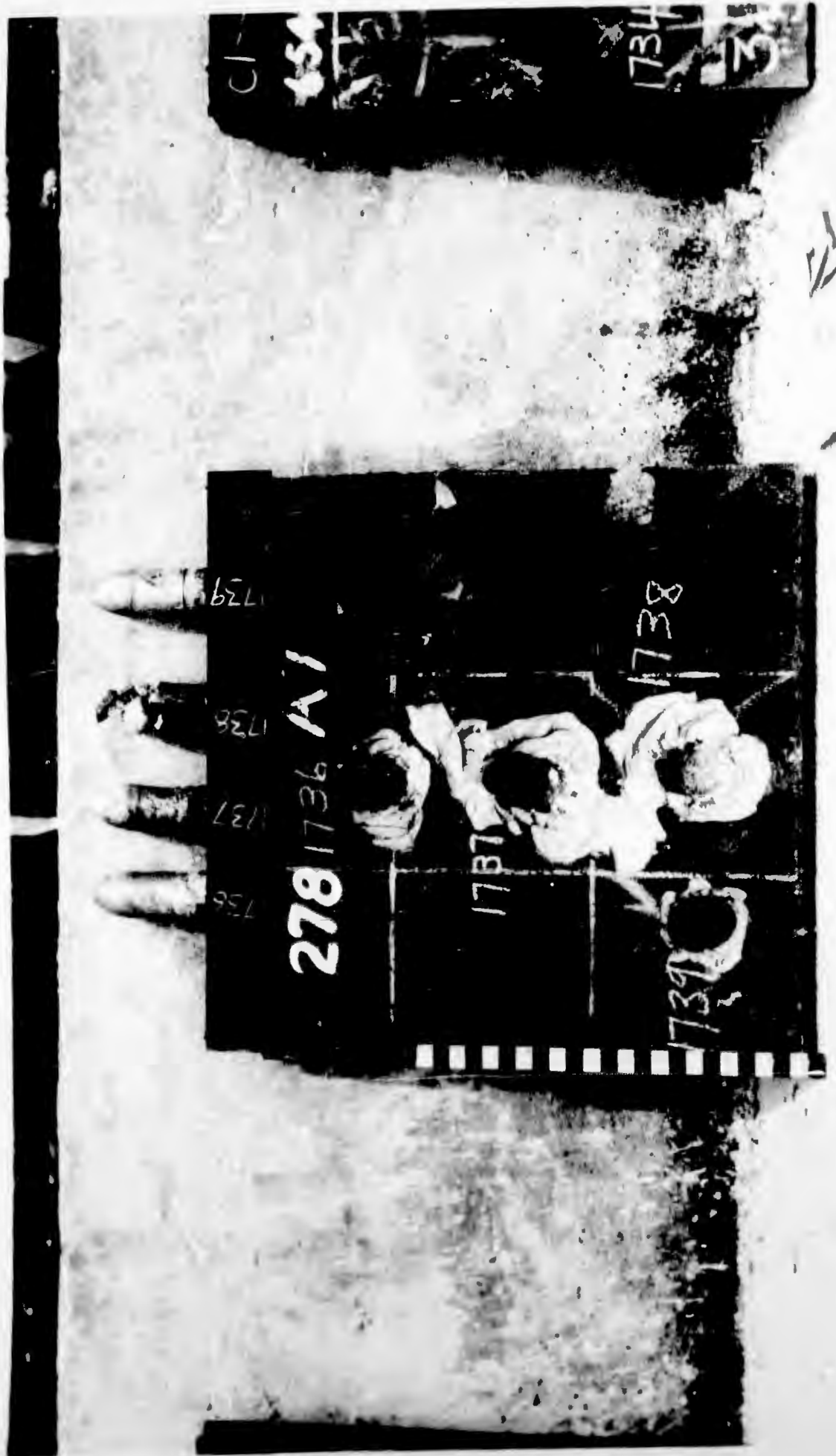
1798	APL 288	3"13	20°20'	1858	Inc.	Ineff. Shat- tered.	109
1794	APL	3"15	19°40'	1915	Par.	Ineff. Shat- tered.	113
1793	APL	3"15	19°40'	1973	Comp.	Ineff. Nose shattered.	116
1795	APL	3"15	19°40'	2003	Comp.	Eff. Nose broken	118
1796	APL	3"13	20°00'	2049	Comp.	Eff. Nose broken	121

Beth. M61 (Group D) Penetration Limit F = 55,800±800(115±2%)
Effective Limit F = 57,000±500(117±1%)

APPENDIX B

Photographs of Ballistic Test Plates

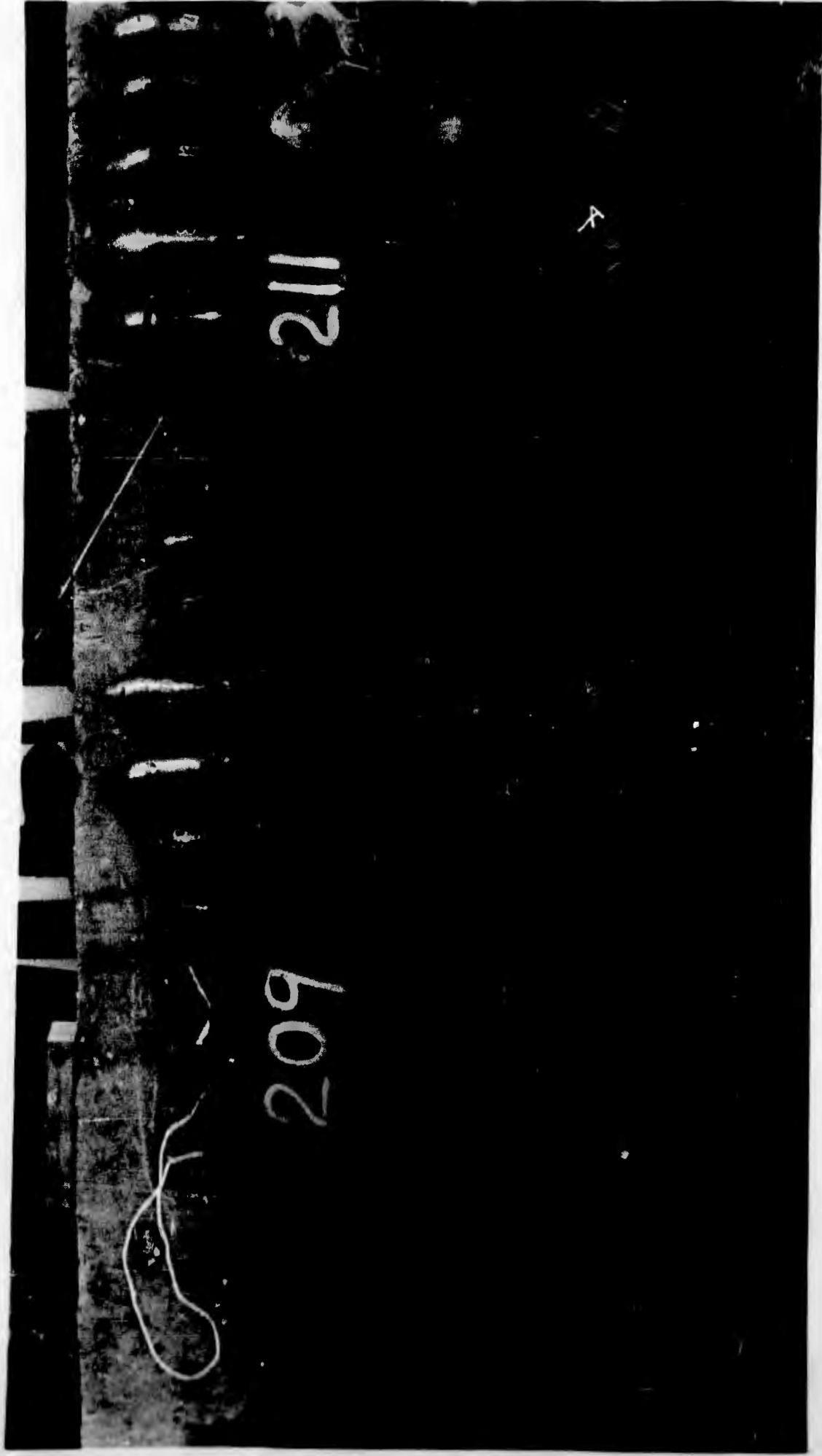
NPG PHOTO NO. 1048 (APL) - APL Plate No. 278 (Midvale 3" Class A No. 7226-2) vs.
 Beth. 14.99 lb. 3" M61 capped AP projectiles at 20° obliquity. FRONT VIEW. See
 NPG Photo No. 1049 APL for back view.
 B.I.No. "e" "g" S.V.f.s. %
 1736 APL 3:20 19°30' 1857 108
 1737 3:20 20°10' 1777 103
 1738 3:20 20°20' 1807 104
 1739 3:20 20°10' 1843 106
 Proj. Cond.
 Eff. Base and body scarred.
 Nose intact.
 Eff. Bent. Heavy base dent.
 Nose intact.
 Ineff. Shattered.
 Eff. Heavy base dent. Body
 scarred. Nose intact.
 - CONFIDENTIAL -
 2-3 September 1943



NPG PHOTO NO. 1301 (APL) - APL Plate No. 209 (Carn.-Ill. 3" Class "A" No. KE630) vs. Beth. 14.2 lb. 3" M61 capped AP projectiles at 20° obliquity. FRONT VIEW. See NPG Photo No. 615 (APL) for back view and NPG Photo No. 614 (APL) for previous impacts.

B.I. No.	"W"	"Q"	S.V. f.s.	Pene. Comp.	Proj. Cond.
1209 APL	3W18	20°20'	2045	Comp.	Effective - Whole.
1210	3W23	20°10'	1924	Comp.	Effective - Whole.
1211	3W22	19°45'	1771	7/8"	Ineffective - Shattered.
1212	3W21	19°25'	1874	1-1/4"	Ineffective - Shattered.

15-16 January 1943
 - CONFIDENTIAL -



NPG PHOTO NO. 1063 (APL) - APL Plate.No. 275 (Carn.-Ill. 3" Class "A" No. JJ256)
 vs. Beth. 14.99 lb. 3" M61 AP projectiles at 20° obliquity. FRONT VIEW. See

NPG Photo No. 1061 APL for back view and NPG Photos Nos. 1025-26 APL for

previous impacts.

B.I.No.	Wt.	Wt.	S.V.f.s.	%	Pene.	Proj. Cond.
1766 APL	3:21	19°40'	2014	116	Inc.	Ineff. Shattered.
1767	3:21	19°40'	2087	121	Ineff.	Nose gone.
1768	3:21	19°30'	2169	126	Ineff.	Split in two.

9-10 September 1943

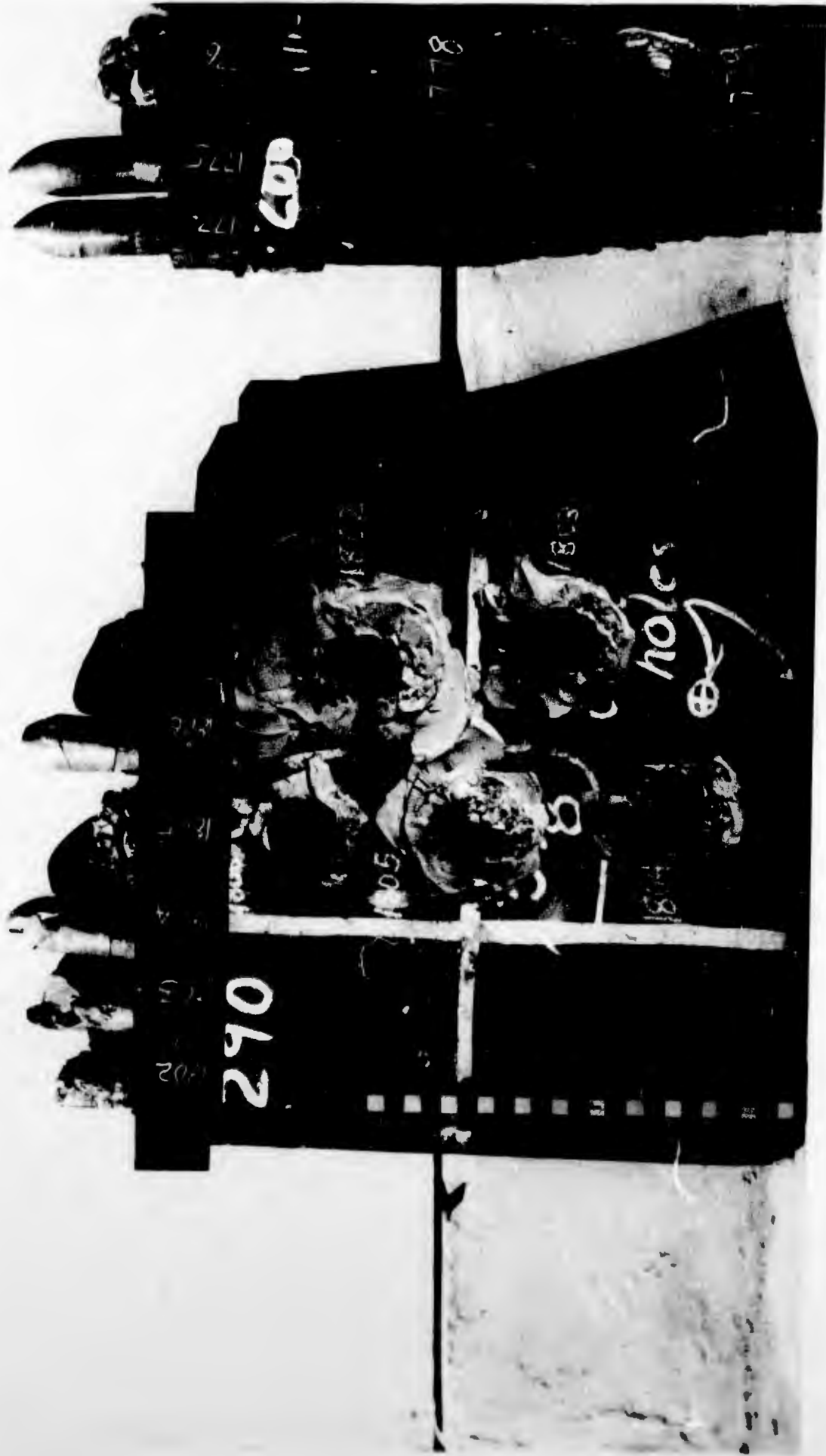
- CONFIDENTIAL -



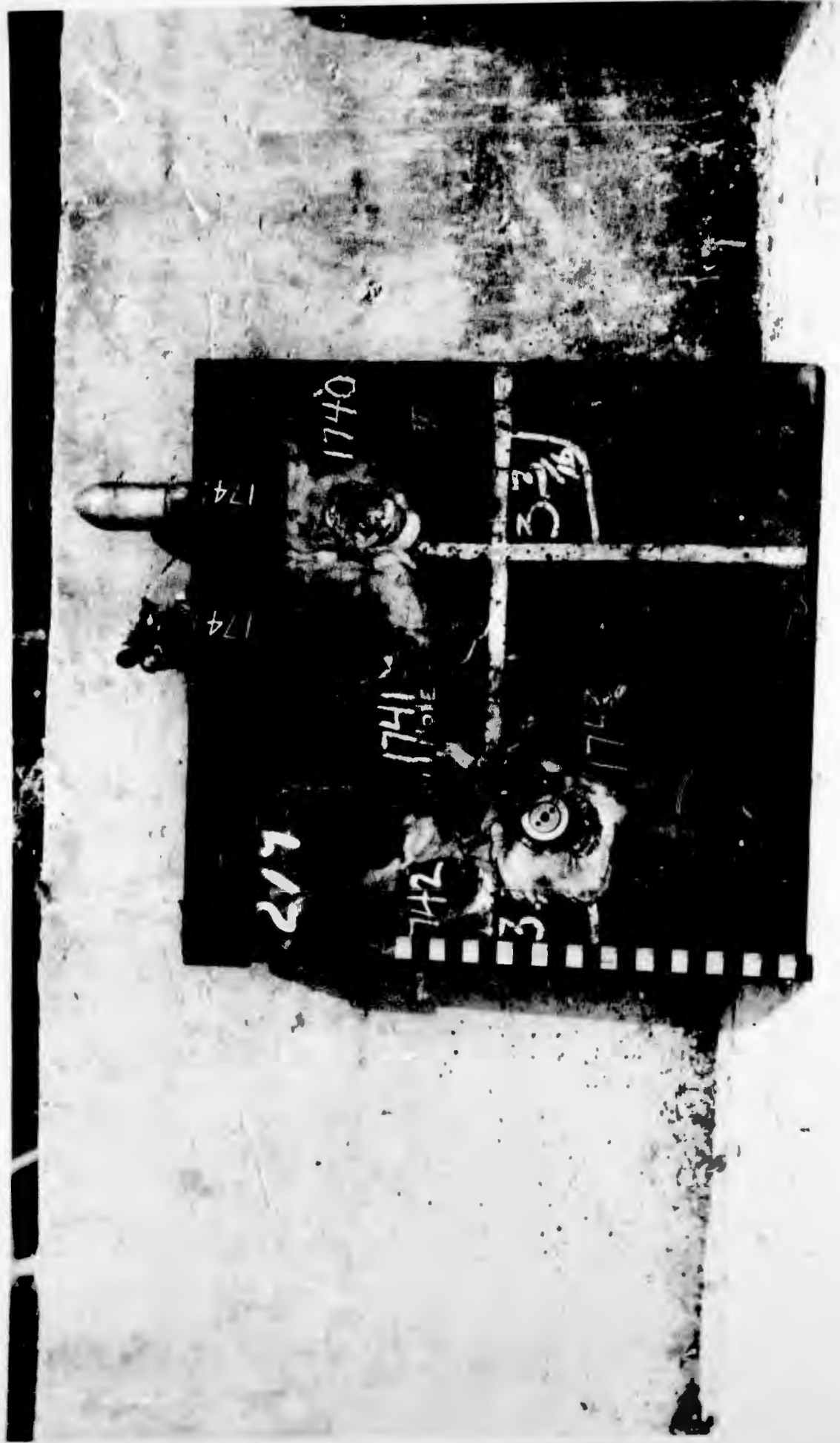
NPG PHOTO NO. 1076 (APL) - APL Plate No. 290 (Curn.-Ill. 3" Class "A" No. JJ256) vs.
 Beth.14.99 lb. 3" M61 AP capped projectiles at 20° obliquity. FRONT VIEW. See
 NP? Photo No. 1077 APL for back view.
 B.I.No. "e" "g" S.V.f.s. "p" Pene. Proj. Cond.
 1802 A7L 3742 20°10' 2088 114 Partial Ineff.Nose shattered. Body cracked
 1803 3742 20°00' 2157 113 Comp. into cavity.
 1804 3742 19°50' 2177 119 Comp. Ineff. Nose wiped off. Cavity exposed.
 1805 3742 20°00' 1998 109 1-3/4" Eff. Nose wiped off.
 1806 3742 20°00' 2226 122 Comp. Ineff. Shattered.
 Probably ineff. Nose wiped off. Body
 cracks.

17-18 September 1943

- CONFIDENTIAL -



NPG PHOTO NO. 1052 (APL) - APL Plate No. 279 (Cern.-Ill. 3" Class A No. JJ298) vs. Beth. 14.99 lb. 3" M61 AP projectiles at 20° obliquity.
 FRONT VIEW. See NPG Photo No. 1053 APL for back view.
 B.I.No. 1740 APL 3715 20°00' 1887 S.V.f.s. 2 Pens. Proj. Cond.
 1741 3715 20°00' 2050 120 CP Ineff. Shattered. Eff. Base chipped. Body scarred. Nose intact.
 1742 3715 20°00' 1983 116 SIP Ineff. Nose split into cavity.
 1743 3715 20°10' (est) 1920 118 SIP Prob. Eff. Nose chewed off.
 3 September 1943 (est.) - CONFIDENTIAL -

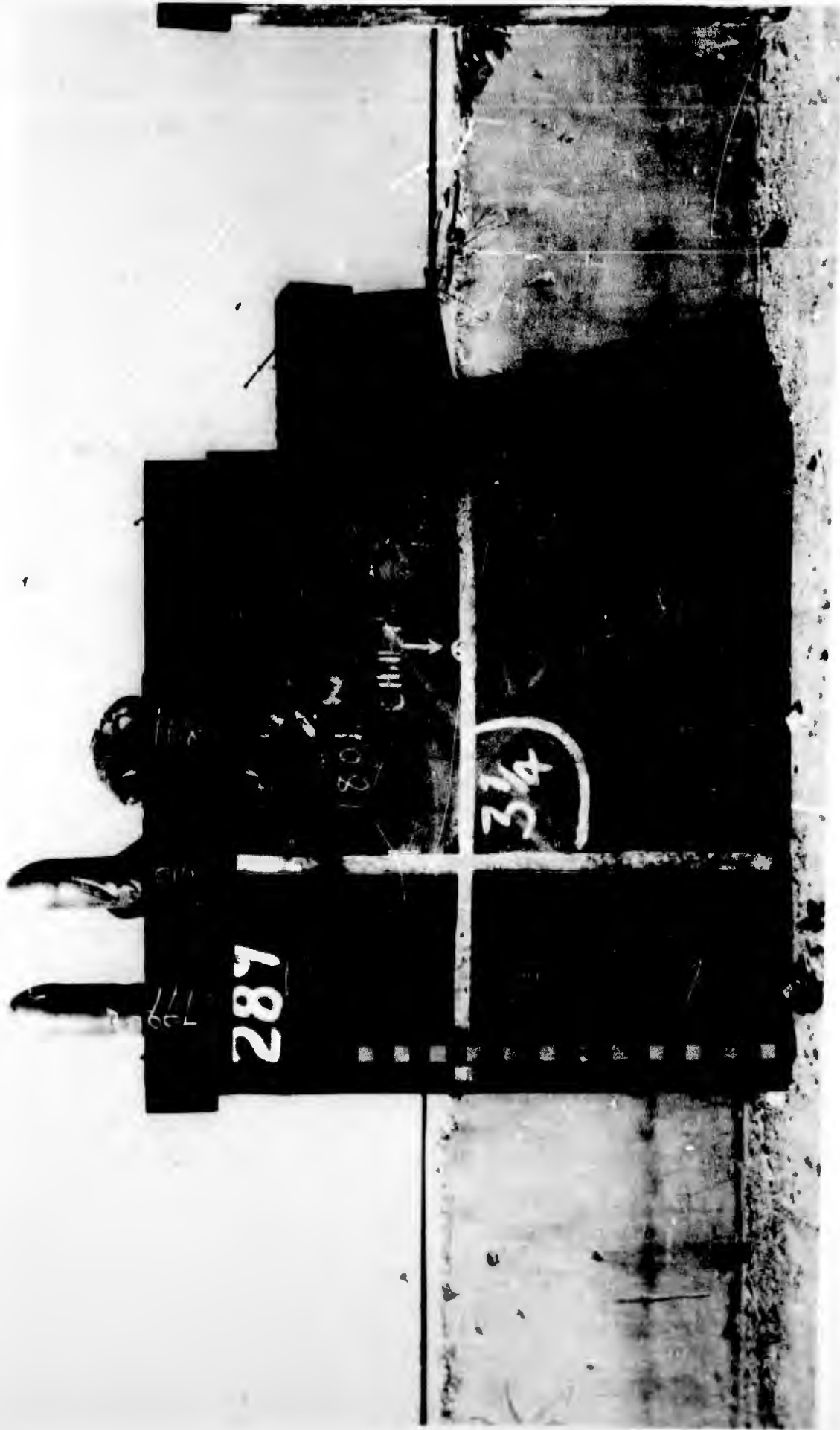


NPG PHOTO NO. 1080 (APL) - APL Plate No. 289 (Carn.-Ill. 3" Class A No. JJ298) vs.
 Beth. 14.99 lb. 3" M61 AP Projectiles at 20°. FRONT VIEW. See NPG Photo No. 1081
 APL for back view.

B.I.No.	"w"	"g"	S.V.	f.s.	Pene.	Proj. Cond.
1799 APL	3:18	20°10'	1993	116	Comp.	Eff. Nose slightly cracked.
1800	3:18	20°00'	1953	114	Comp.	Eff. Nose cracked.
1801	3:18	20°30'	1886	109	Inc.	Ineff. Shattered.

16 September 1943

- CONFIDENTIAL -

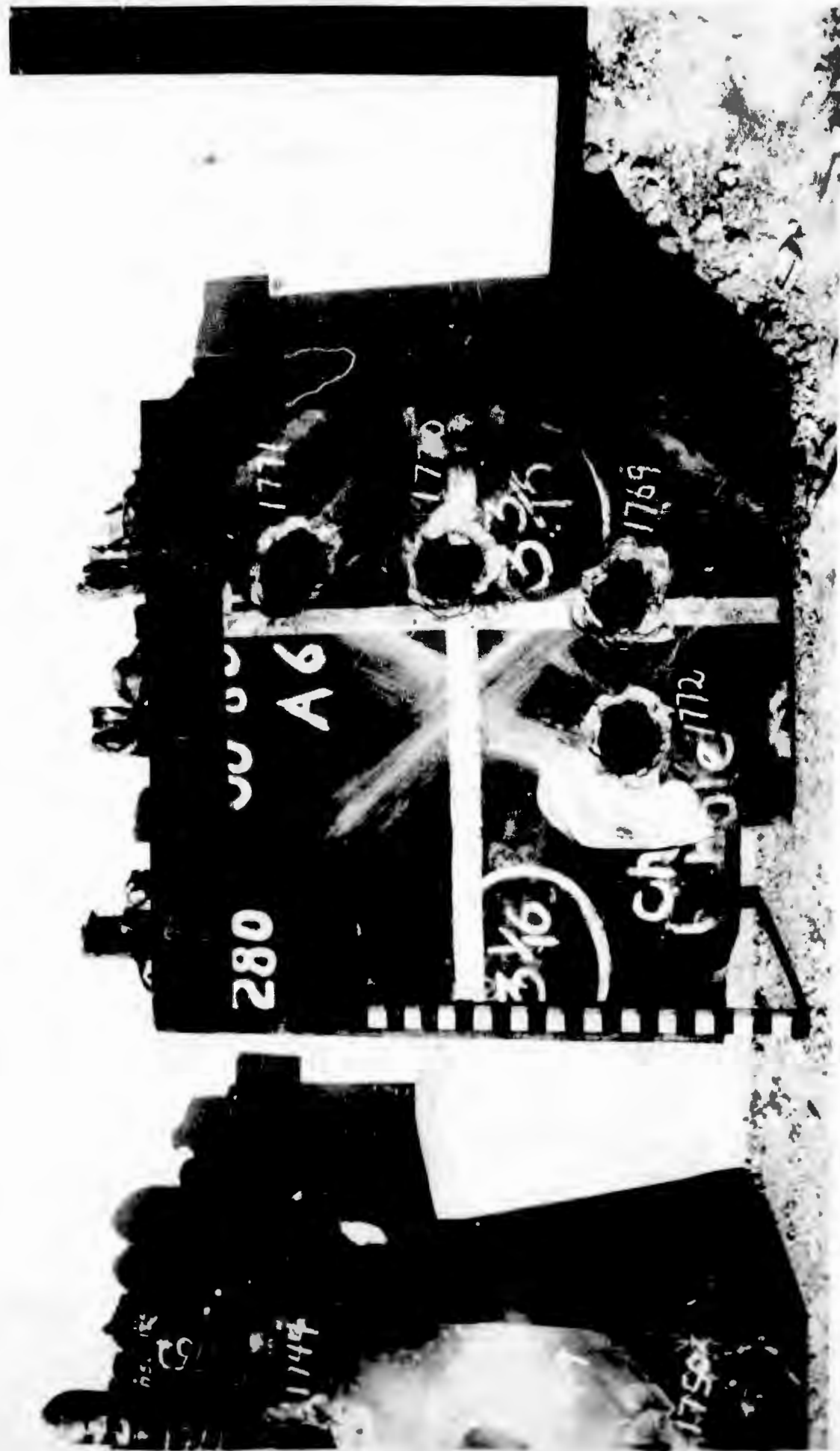


MPG PHOTO NO. 1066 (AFL) - APL Plate No. 280 (Carn.-Ill. 3" Class "A" No. JJ654) vs. Beth. 14.99 lb. 3" M61 capped AP projectiles at 20° obliquity. FRONT VIEW. See NPG Photo No. 1067 APL for back view.

B.I.No.	"e"	"g"	S.V.f.f.s.	%	Pene.	Proj. Cond.
1769 APL	3:12	19°30'	1963	116	Partial	Ineff. Shattered.
1770	3:11	19°50'	2032	120	Comp.	Not recovered.
1771	3:13	19°40'	2023	120	Partial	Ineff. Shattered.
1772	3:12	19°30'	2113	125	Comp.	Shattered.

10 September 1943

- CONFIDENTIAL -



NPG PHOTO NO. 1084 (APL) - APL Plate No. 238 (Carn.-Ill. 3" Class A No. JJ654) vs.
 Beth. 14.99 lb. 3" M61 capped AP projectiles at 20° obliquity. FRONT VIEW. See
 NPG Photo No. 1085 APL for back view and data on impacts 1796-8 APL.
 B.I.No. "w" "g" S.V.f.s. 2 Pene. Proj.Cond.
 1793 APL 3:15 19:40' 1973 116 Comp. Ineff. Nose shattered. Split into cavity.
 1794 3:15 19:40' 1915 113 Partial Ineff. Shattered.
 1795 3:15 19:40' 2003 118 Comp. Eff. Nose chipped. Body cracked.
 15-16 September 1943

- CONFIDENTIAL -



APPENDIX C

Hardness Distribution Curves Through Plate Cross Sections

NPG Photo No. 1302 (APL)
CONFIDENTIAL

HARDNESS DISTRIBUTION THROUGH
CROSS SECTION OF MIDVALE
3" CLASS "A" ARMOR PLATE

22 December 1943

1226-2

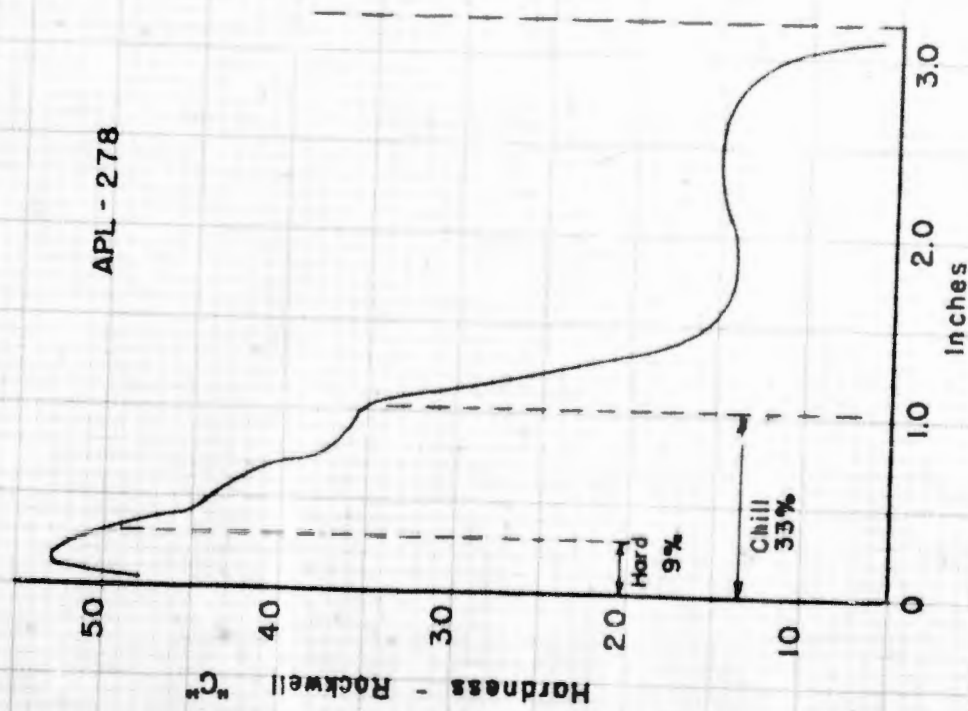


Fig. 9

NPG Photo No. 1303 (APL)
CONFIDENTIAL

22 December 1943

HARDNESS DISTRIBUTION THROUGH
CROSS SECTION OF CARNEGIE
3" CLASS "A" ARMOR PLATE

EEB30

APL - 209

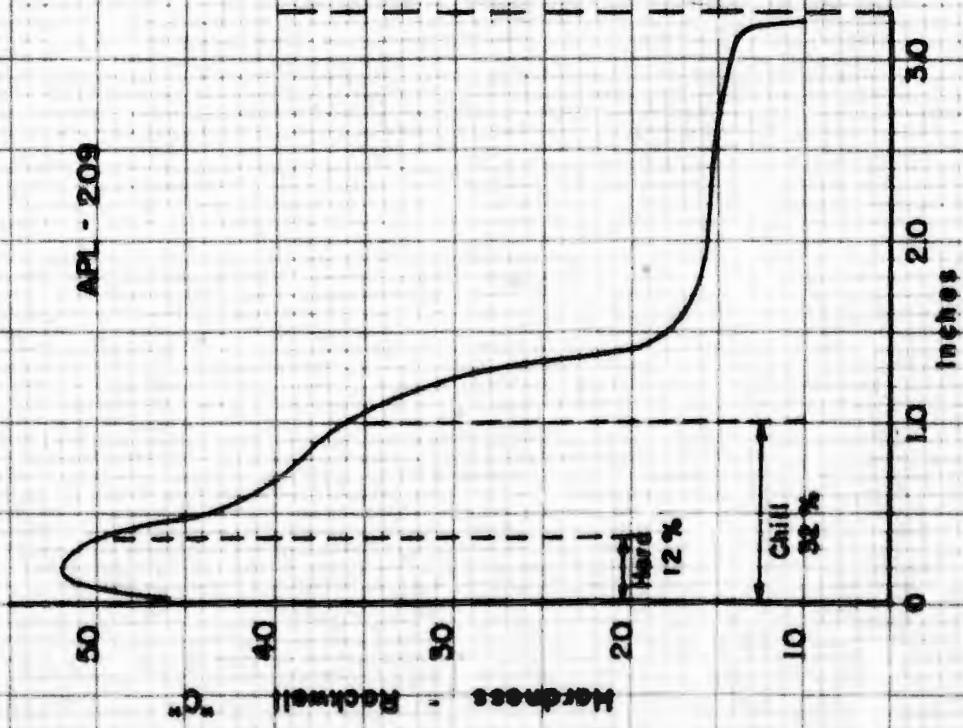


Fig. 10

NPG Photo No 1304 (APL)

CONFIDENTIAL

HARDNESS DISTRIBUTION THROUGH
CROSS SECTIONS OF CARNEGIE
3" CLASS "A" ARMOR PLATE

22 December 1943

JJ256

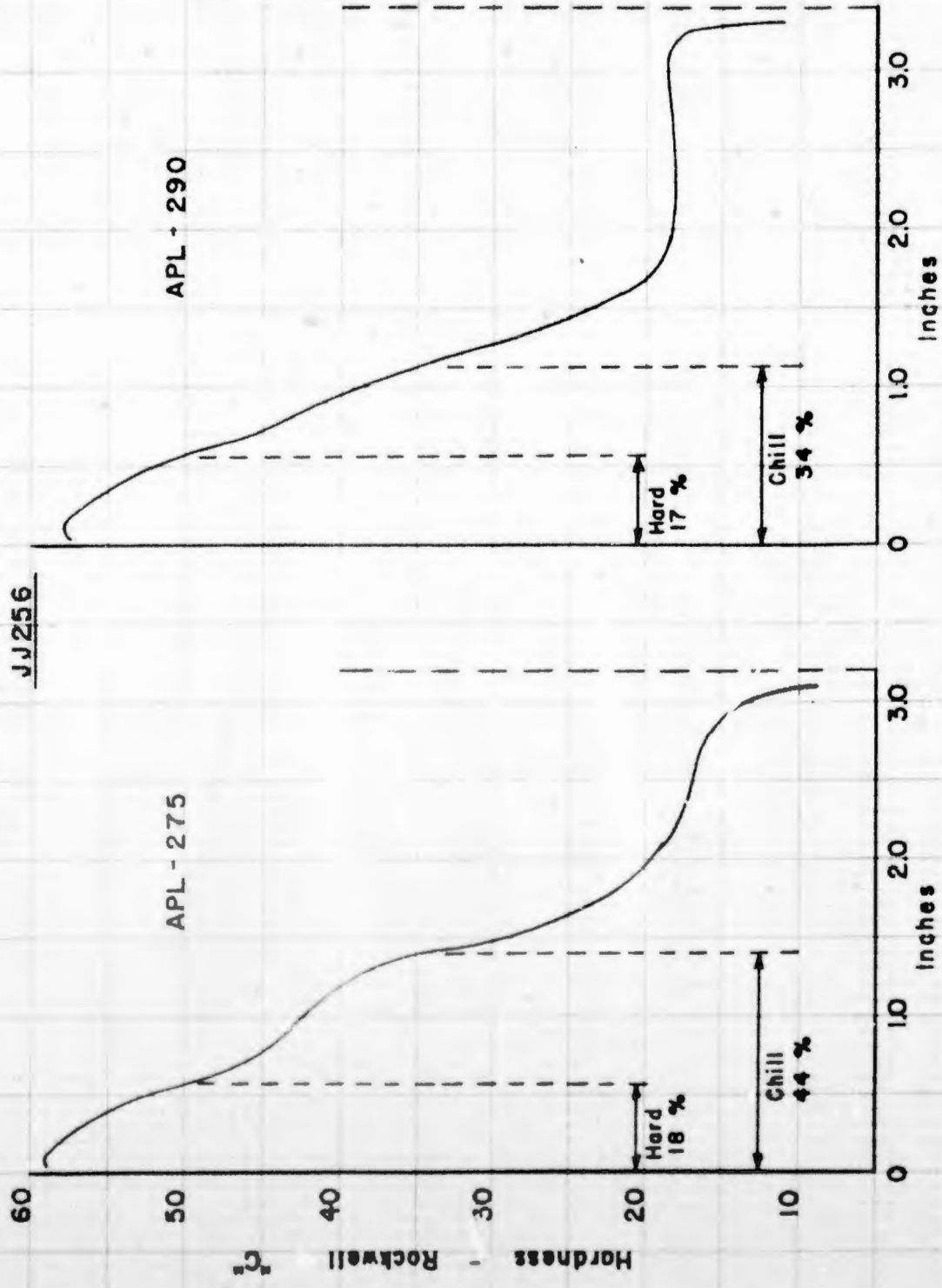


Fig. II

NPG Photo No. 1305 (APL)

CONFIDENTIAL

HARDNESS DISTRIBUTION THROUGH
CROSS SECTIONS OF CARNEGIE
3rd CLASS "A" ARMOR PLATE

22 December 1943

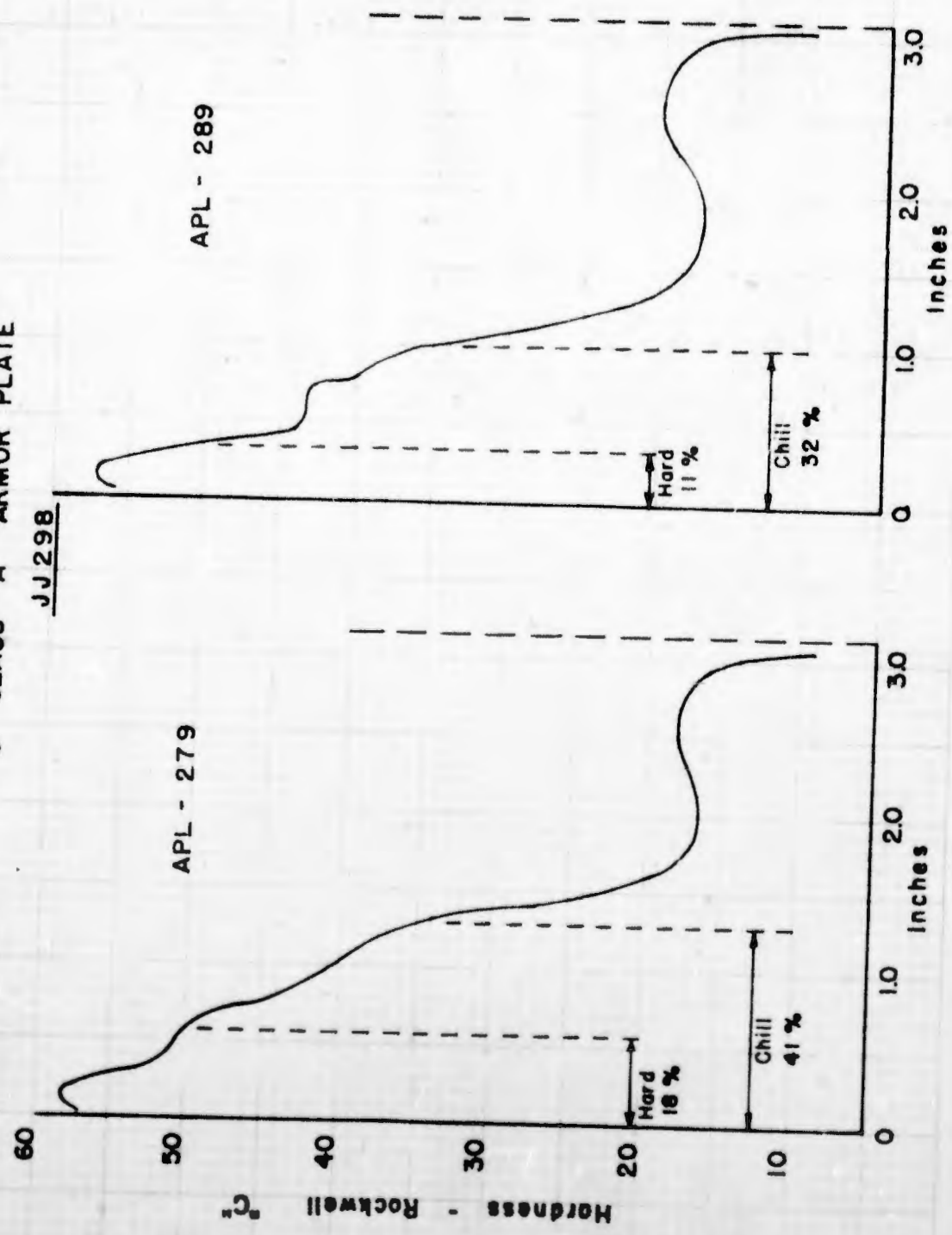


Fig. 12

NPG Photo No. 1306 (APL)

CONFIDENTIAL

HARDNESS DISTRIBUTION THROUGH
CROSS SECTIONS OF GARNET
3" CLASS "A" ARMOR PLATE

22 December 1943



Fig. 13

APPENDIX D

Macro-etched Cross Sections of Plates.

23 December 1943

MACROETCHED CROSS SECTION OF MIDVALE
3" CLASS "A" PLATE
7226-2

(Actual Size)

Etch A: 10% Ammonium Persulphate - Swab - 30 Secs.
Etch B: 38% HCl, 12% H₂SO₄, 50% H₂O - 2-3Hours - 160°F

APL - 278

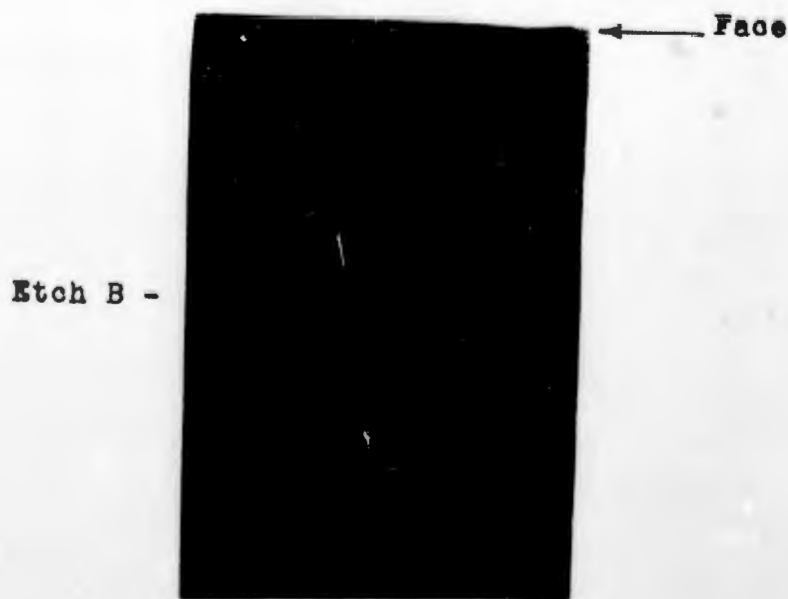
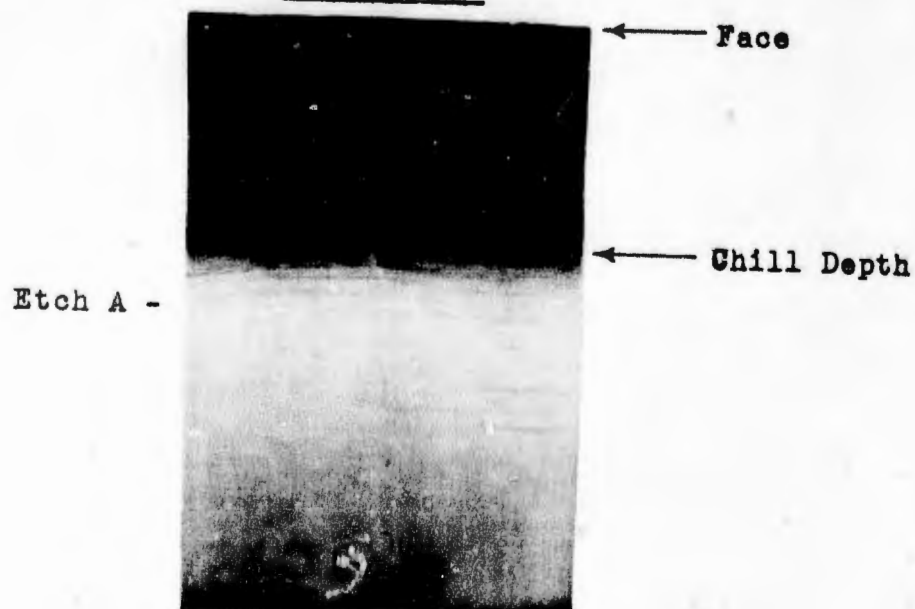


Fig. 14

23 December 1943

MACROETCHED CROSS SECTION OF CARNEGIE
3" CLASS "A" PLATE
EE630

(Actual Size)

Etch A: 10% Ammonium Persulphate - Swab - 30 Secs.

Etch B: 38% HCl, 12% H₂SO₄, 50% H₂O - 2-3 Hours - 160°F

APL - 209

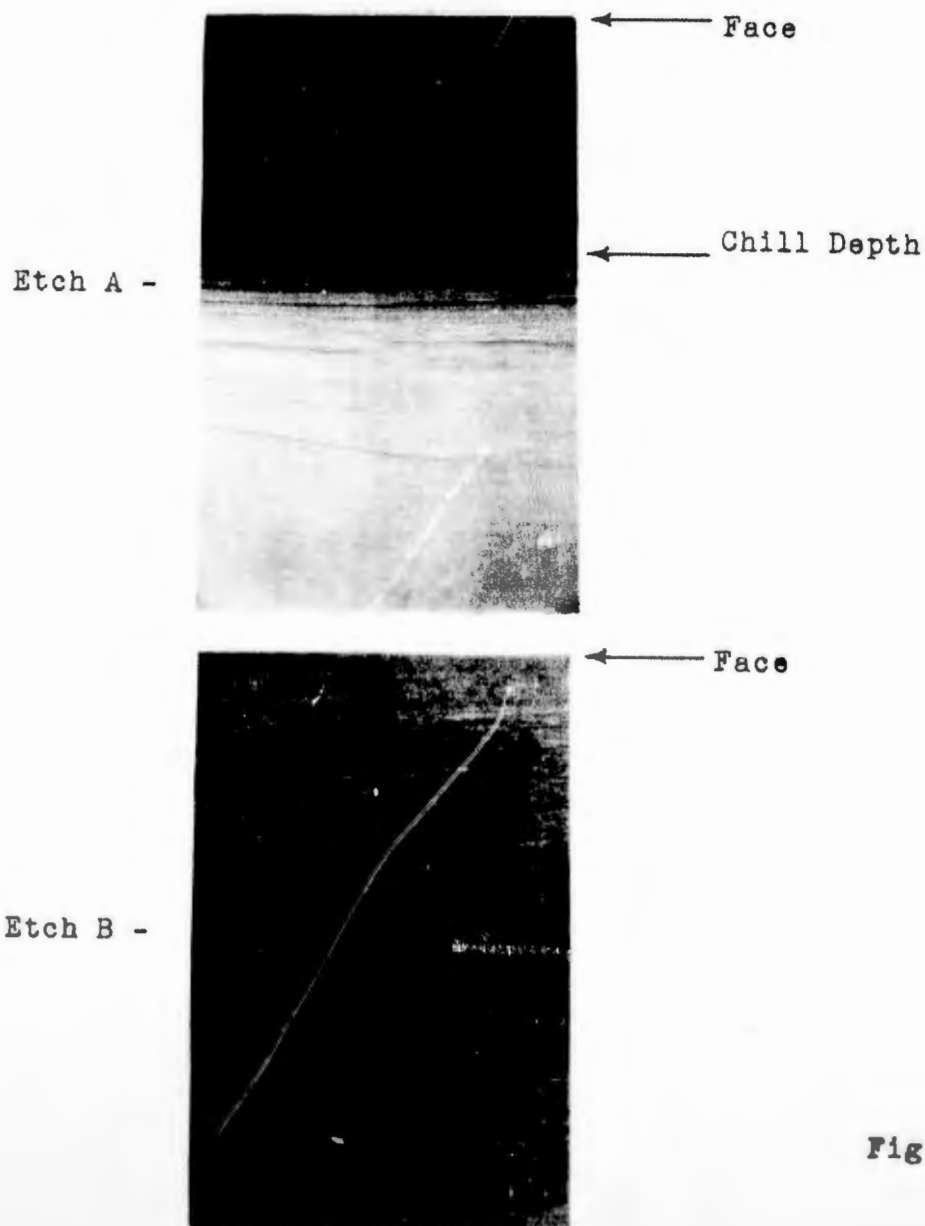


Fig. 15

MACROETCHED CROSS SECTIONS OF CARNEGIE
3" CLASS "A" PLATE
JJ256

(Actual Size)

Etch A: 10% Ammonium Persulphate - Swab - 30 Secs.

Etch B: 38% HCl, 12% H₂SO₄, 50% H₂O - 2-3 Hours - 160°F

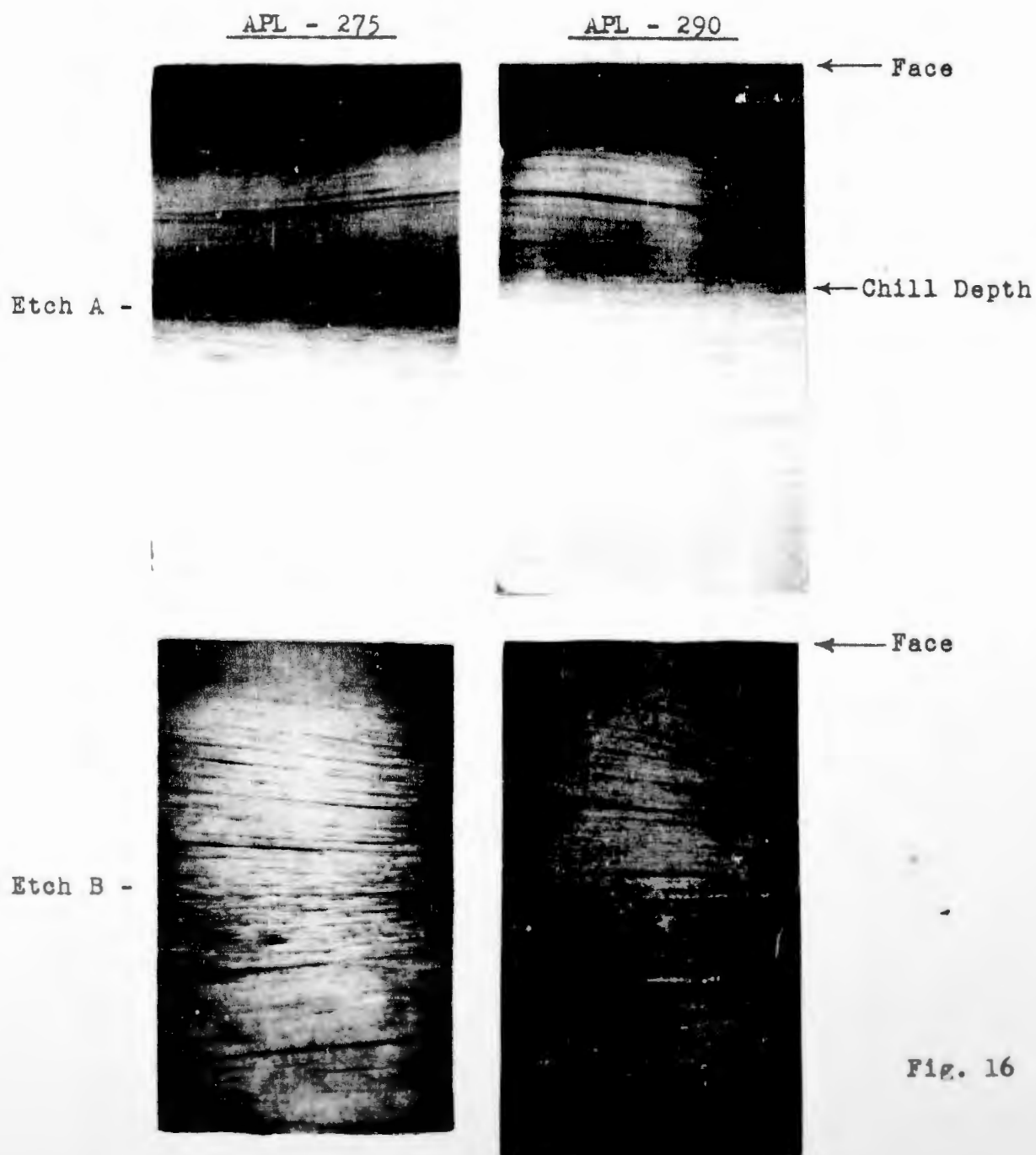
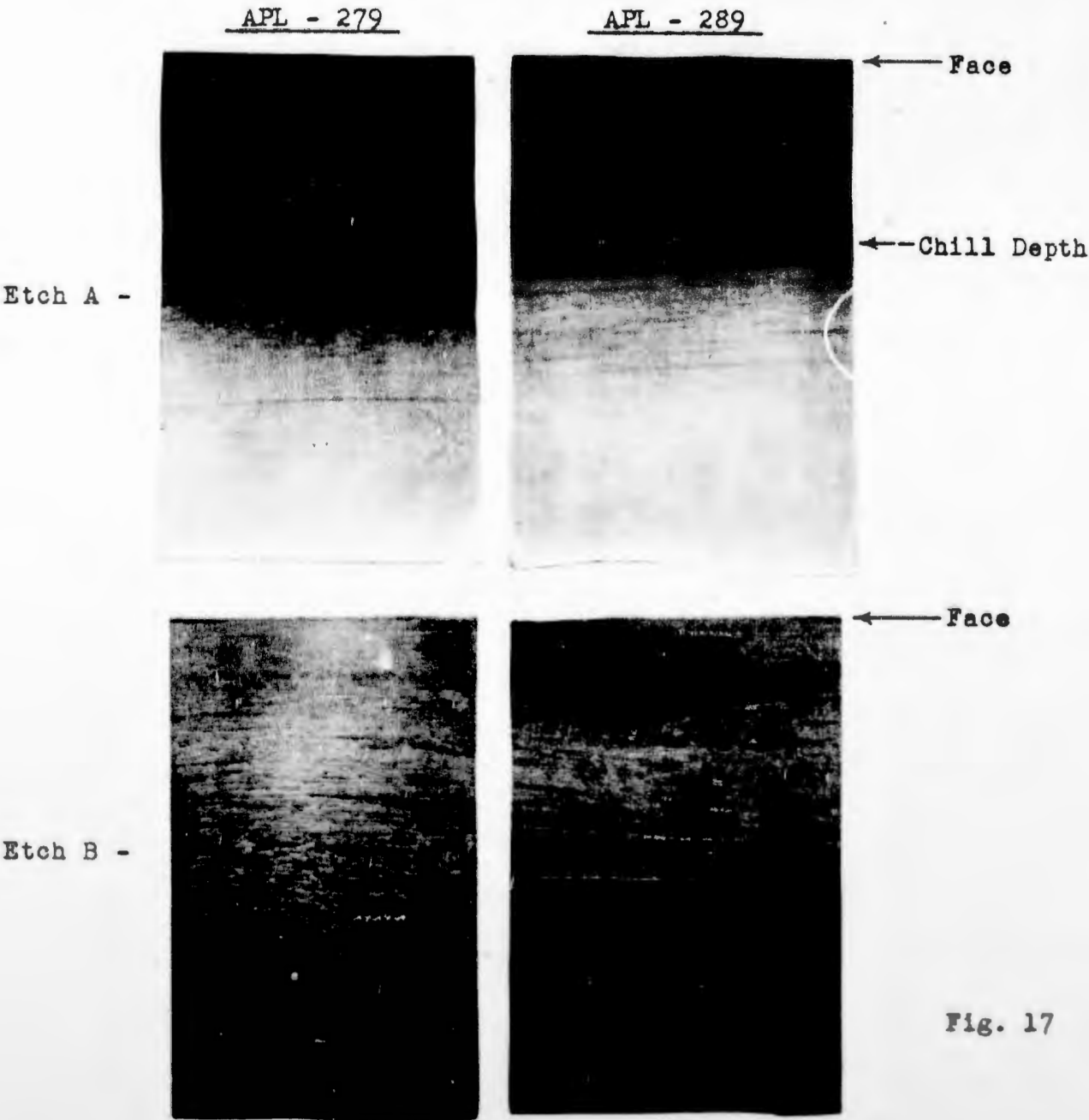


Fig. 16

MACROETCHED CROSS SECTIONS OF CARNEGIE
3" CLASS "A" PLATE
JJ298

(Actual Size)

Etch A: 10% Ammonium Persulphate - Swab - 30 Secs.
Etch B: 38% HCl, 12% H₂SO₄, 50% H₂O - 2-3 Hours - 160°F

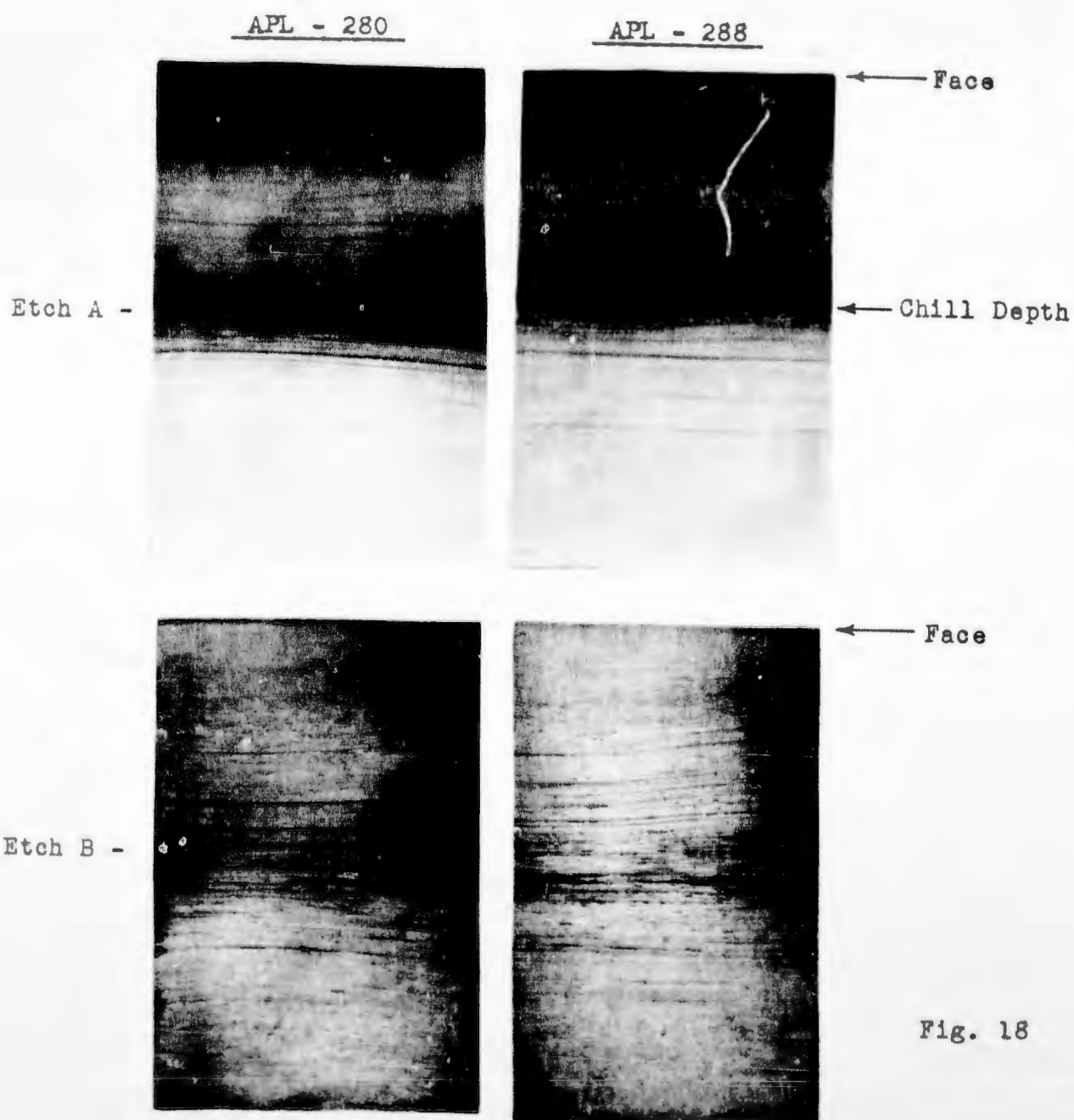


23 December 1943

MACROETCHED CROSS SECTIONS OF CARNEGIE
3" CLASS "A" PLATE
JJ654

(Actual Size)

Etch A: 10% Ammonium Persulphate - Swab - 30 Secs.
Etch B: 38% HCl, 12% H₂SO₄, 50% H₂O, - 2-3 Hours - 160°F



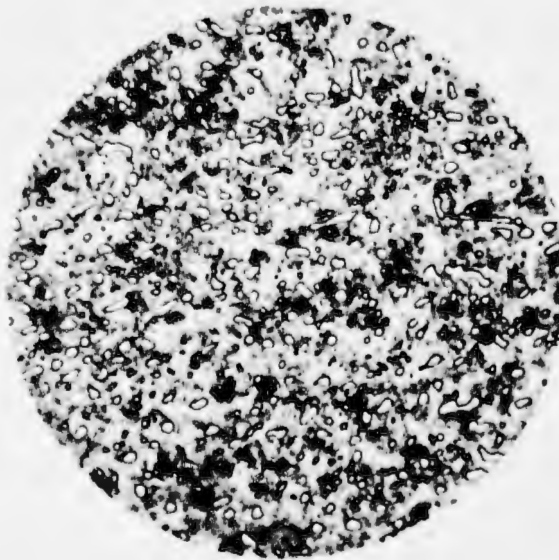
APPENDIX E

Representative Photomicrographs of Face and Back of Plates.

MICROSTRUCTURE OF FACE AND BACK
OF MIDVALE 3" CLASS "A" PLATE
7226-2

Magnification 1000X -- Picral-Nital Etch

Face



M-336

Back



M-337

Fig. 19

NPG Photo No. 1314 (APL)

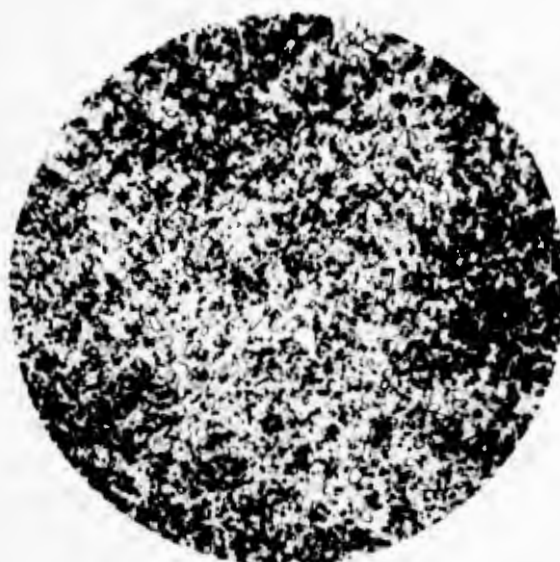
-CONFIDENTIAL-

22 December 1943

MICROSTRUCTURE OF FACE AND BACK
OF CARNEGIE 3" CLASS "A" PLATE
EE630

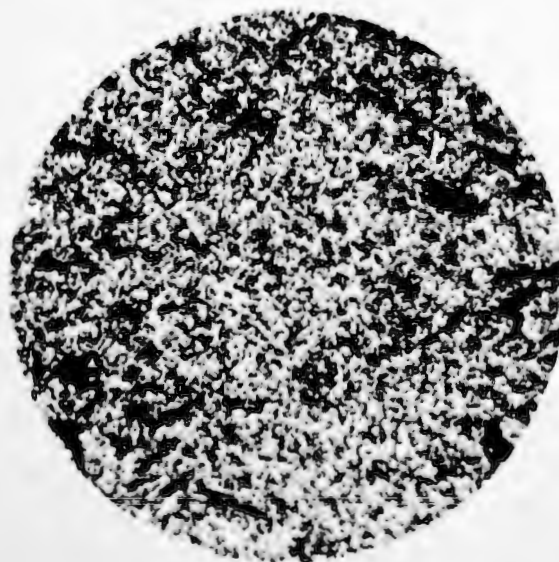
Magnification 1000X -- Picral-Nital Etch

Face



M-160

Back



M-338

Fig. 20

MICROSTRUCTURE OF FACE AND BACK
OF CARNEGIE 3" CLASS "A" PLATE
JJ256

Magnification 1000X -- Picral-Nital Etch

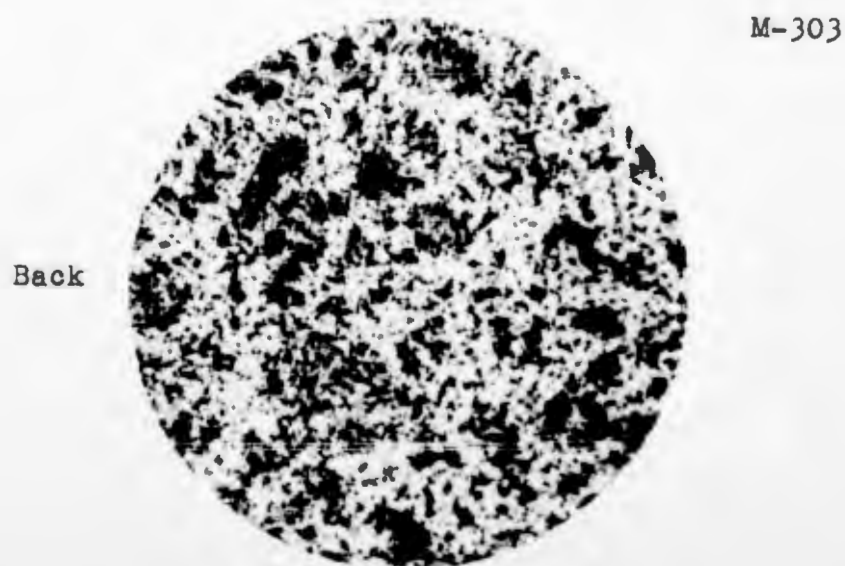
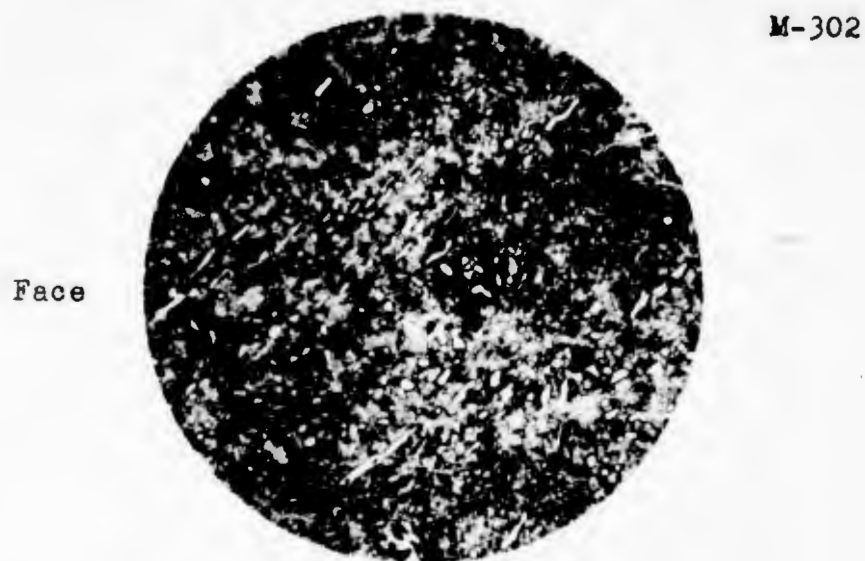


Fig. 21

NPG Photo No. 1316 (APL)

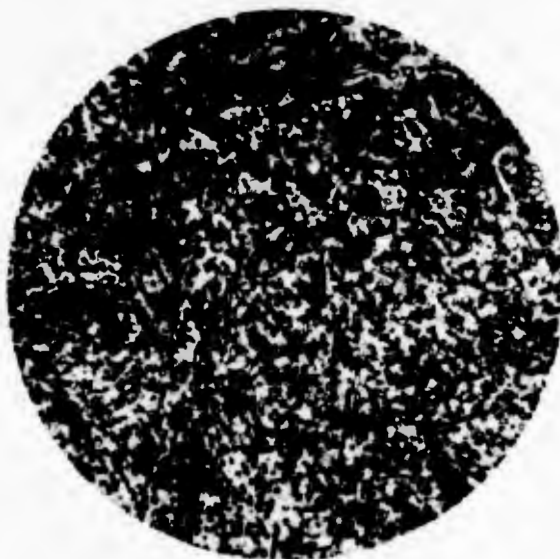
-CONFIDENTIAL-

22 December 1943.

MICROSTRUCTURE OF FACE AND BACK
OF CARNEGIE 3" CLASS "A" PLATE
JJ298

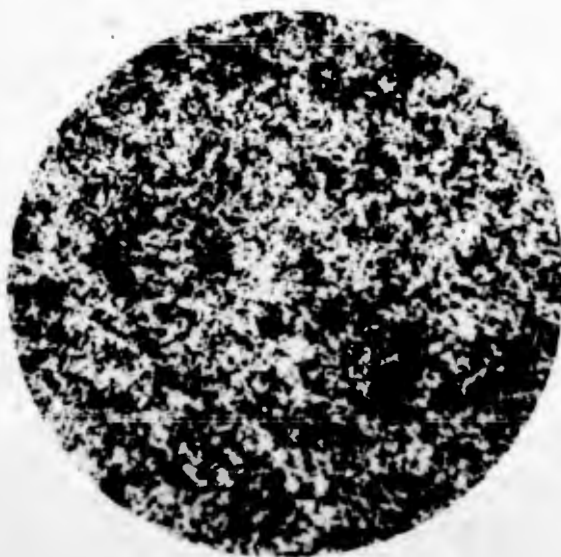
Magnification 1000X -- Picral-Nital Etch

Face



M-305

Back



M-306

Fig. 22

MICROSTRUCTURE OF FACE AND BACK
OF CARNEGIE 3" CLASS "A" PLATE
JJ654

Magnification 1000X -- Picral-Nital Etch

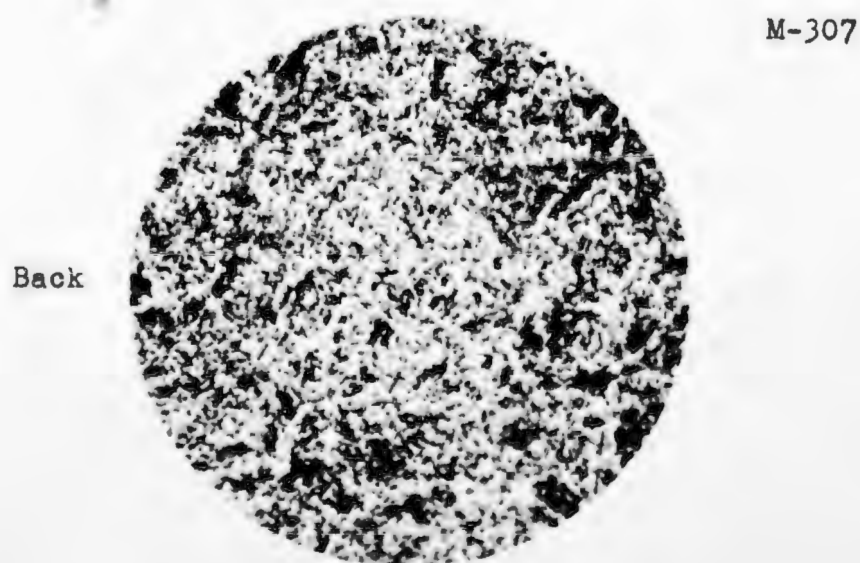
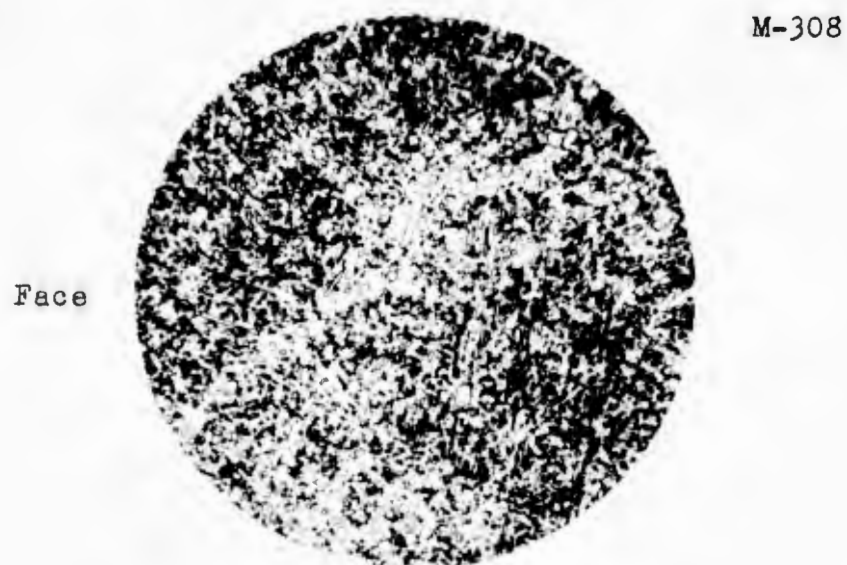


Fig. 23

APPENDIX F

CHEMICAL COMPOSITION
TENSILE PROPERTIES OF BACK
CHILL TEST RESULTS.

Chemical Analysis:

<u>Plate</u>		<u>C</u>	<u>Mn</u>	<u>P</u>	<u>S</u>	<u>Si</u>	<u>Ni</u>	<u>Cr.</u>
7226-2 Midvale	T-	0.32	0.27	.017	.022	.07	3.85	1.64
	B-	0.32	0.27	.016	.021	.07	3.86	1.64
	APL	0.30	0.32	.012	.026	.07	3.68	1.64
ET630 Carnegie	T-	0.33	0.28	.019	.025	.07	3.91	1.98
	B-	0.32	0.26	.018	.026	.07	3.71	1.80
	APL	0.34	0.26	.017	.024	.07	3.75	2.02
JJ256 Carnegie	T-	0.36	0.21	.015	.027	.07	3.68	1.66
	B-	0.33	0.20	.014	.026	.06	3.68	1.66
	APL	0.33	0.23	.017	.022	.08	3.55	1.66
JJ298 Carnegie	T-	0.37	0.21	.014	.028	.07	3.22	1.45
	B-	0.37	0.20	.014	.028	.07	3.20	1.41
	APL	0.35	0.20	.018	.022	.07	3.18	1.43
JJ654 Carnegie	T-	0.35	0.20	.013	.030	.09	3.68	1.74
	B-	0.34	0.22	.010	.026	.09	3.70	1.74
	APL	0.33	0.21	.015	.017	.08	3.65	1.74

Tensile Properties of Back:

<u>Plate</u>	<u>APL No.</u>	<u>Y.P.</u>	<u>T.S.</u>	<u>Elong.</u>	<u>R.A.</u>
7226-2 Midvale	T-	90,000	109,500	27.0	69.9
	B-	90,500	110,000	26.8	68.5
	APL 278	90,750	108,625	26.3	67.4
EE630 Carnegie	T-	83,140	107,600	27.0	69.3
	B	80,880	107,300	27.0	63.5
	APL B 209	90,200	104,500	26.4	72.0
JJ256 Carnegie	T-	81,880	104,800	26.5	71.4
	B-	80,280	102,100	27.0	71.4
	APL T 290 B 275	80,400 80,000	100,150 100,100	25.7 28.6	73.9 72.5
JJ298 Carnegie	T-	81,140	106,800	26.5	65.9
	B-	85,080	109,500	29.0	66.5
	APL T 289 B 279	84,900 92,700	105,300 107,300	26.1 26.4	67.5 69.0
JJ654 Carnegie	T-	93,120	116,100	25.0	65.9
	B	89,380	114,300	35.0	64.7
	APL T 288 B 280	93,750 93,250	110,650 111,150	26.1 26.4	70.5 70.3

Chill Test Results: (APL Chill - Depth at "RC" 35)
 (APL Undrillable - Depth at "RC" 50)

<u>Plate</u>	<u>APL</u> <u>No.</u>	<u>Gauge</u> <u>(in.)</u>	<u>Chill</u> <u>(in.)</u>	<u>Chill</u> <u>(%)</u>	<u>Un-</u> <u>drill</u> <u>(in.)</u>	<u>Un-</u> <u>drill</u> <u>(%)</u>
7226-2 Midvale	T-	3-1/8	1-1/2	48	-	-
	B-	3-1/16	1-3/8	39	-	-
APL	278	3.2	1.05	33	.30	9
EE630 Carnegie	T-	3-1/4	1-3/16	34.8	3/4	23.1
	B-	3-1/4	1-1/16	32.7	5/8	19.2
APL	B-209	3.25	1.05	32	.38	11.7
JJ256 Carnegie	T-	3-3/8	1-1/4	37.0	1/2	14.8
	B-	3-5/16	1-9/16	47.1	5/8	18.9
APL	T 290	3.4	1.15	34	.57	16.8
	B 275	3.2	1.40	44	.56	17.5
JJ298 Carnegie	T-	3-3/16	1-1/16	33.3	7/16	13.7
	B-	3-3/16	1-1/2	47.0	5/8	19.5
APL	T-289	3.1	1.0	32	.33	10.7
	B-279	3.15	1.30	41	.55	17.5
JJ654 Carnegie	T-	3-3/16	1-7/16	45.1	1/2	15.6
	B-	3-1/8	1-5/8	52.0	1/2	16.0
APL	T -288	3.1	1.4	45	.60	19.4
	B -280	3.1	1.55	50	.55	17.8

Carbon Gradients: (as reported by manufacturer)

<u>Plate</u>	<u>1/8"</u>	<u>1/2"</u>	<u>3/4"</u>	<u>Back</u>	
7226-2 Midvale	T- 1.04	.58	.32	.32	.32
	B- 1.03	.58	.32	.32	.32
	<u>1/16"</u>	<u>1/4"</u>	<u>1/2"</u>	<u>1"</u>	<u>Back</u>
EE630 Carnegie	T- .91	.80	.40	.33	.33
	B- 1.03	1.08	.48	.37	.32
JJ256 Carnegie	T- .92	.99	.60	.34	.36
	B- 1.36	1.20	.67	.36	.33
JJ298 Carnegie	T- .94	1.23	.64	.38	.37
	B- .98	.96	.60	.38	.37
JJ654 Carnegie	T- .96	1.04	.72	.36	.35
	B- .92	1.05	.59	.35	.34

APPENDIX G

Sketches of Manufacturers' Plate Sectioned for
Small Test Plates.

3" Class "A" Projectile Test Plate

Midvale No. 7226-2

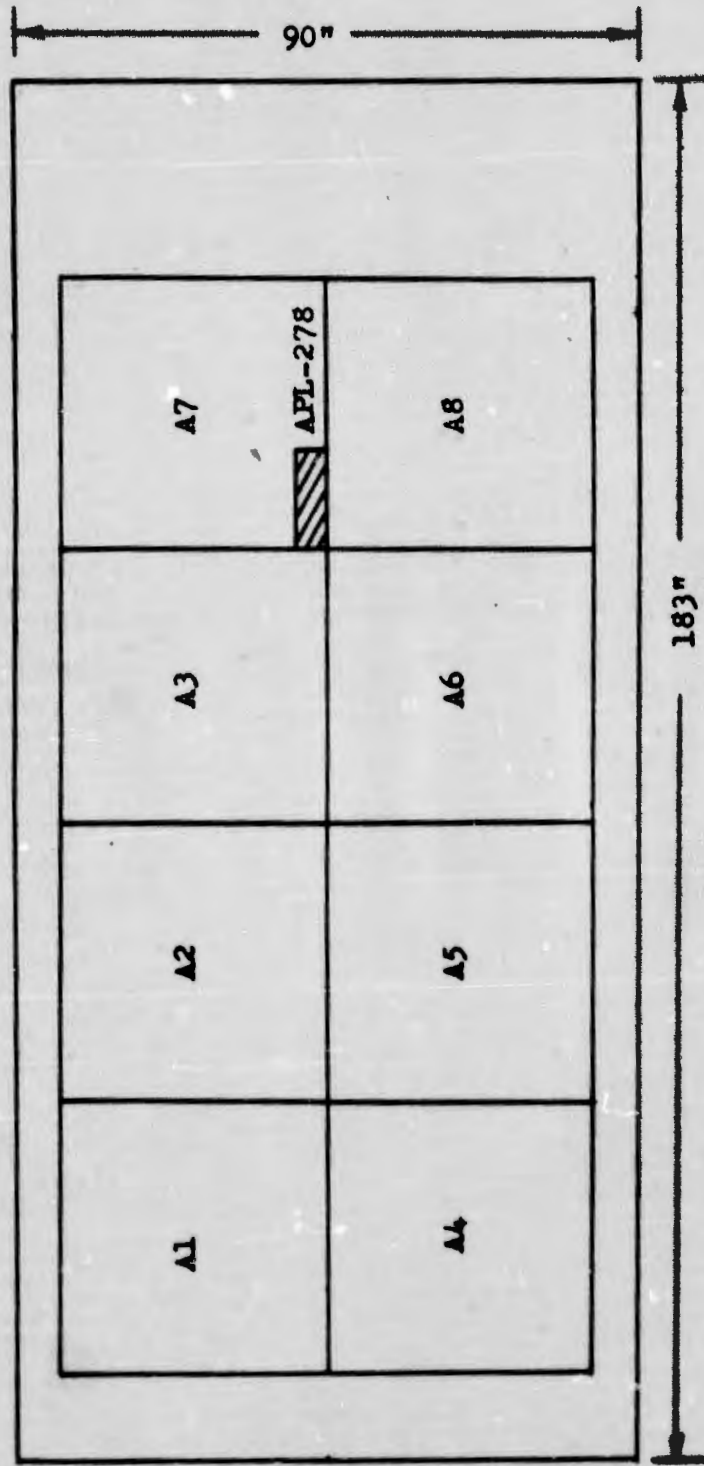


Fig. 24

NPG Photo No. 1307 (APL)

-CONFIDENTIAL-

22 December 1943

3" Class "A" Projectile Test Plate

Carnegie No. EE630

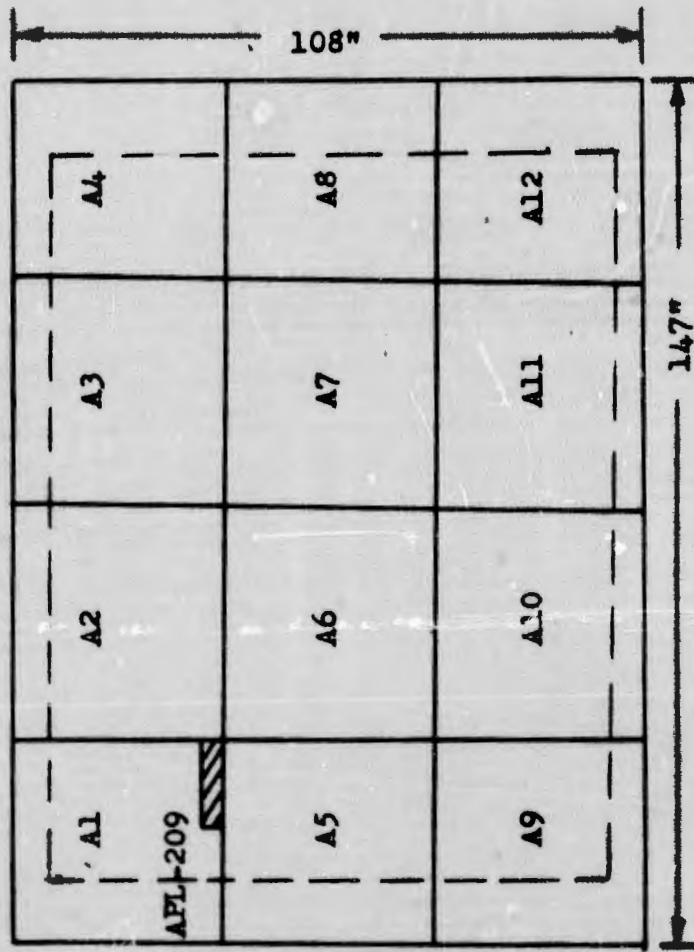


Fig. 25

NPG Photo No. 1308 (APL)

-CONFIDENTIAL-

22 December 1943

CONFIDENTIAL
AD

309 984

FOR
MICRO-CARD
CONTROL ONLY

2

OF

2

Reproduced by

Armed Services Technical Information Agency

ARLINGTON HALL STATION; ARLINGTON 12 VIRGINIA

CONFIDENTIAL

"NOTICE: When Government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the U.S. Government thereby incurs no responsibility, nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto."

3" Class "A" Projectile Test Plate

Carnegie No. JJ256

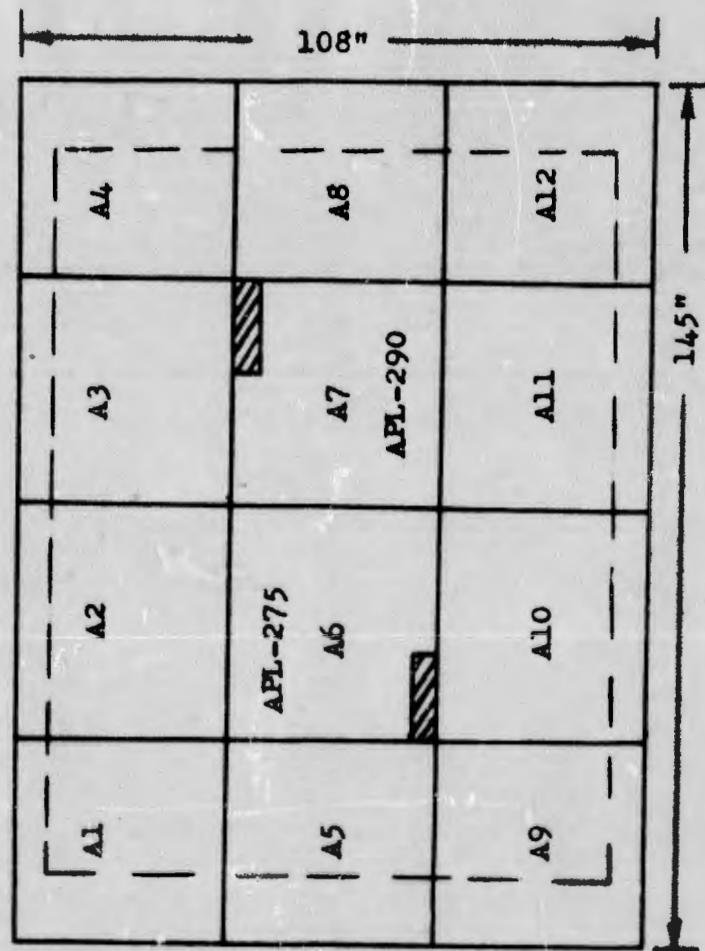


FIG. 26

NPG Photo No. 1309 (APL)

-CONFIDENTIAL-

22 December 1943

3rd Class "A" Projectile Test Plate

Carnegie No. JJ298

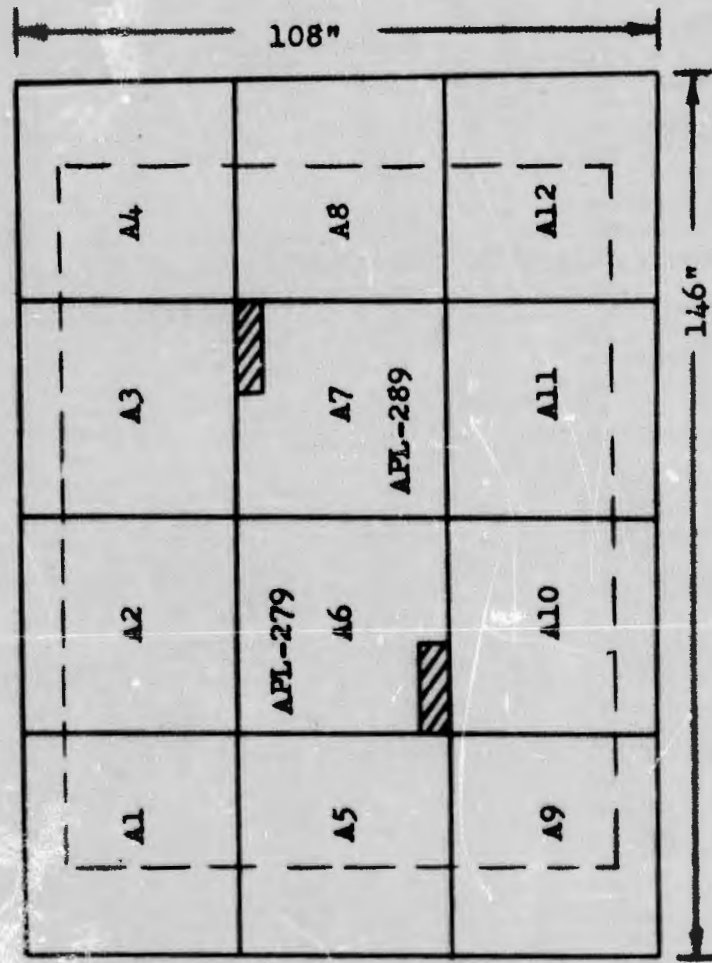


Fig. 27

NPG Photo No. 1310 (APL)

-CONFIDENTIAL-

22 December 1943

Carnegie No. JJ654

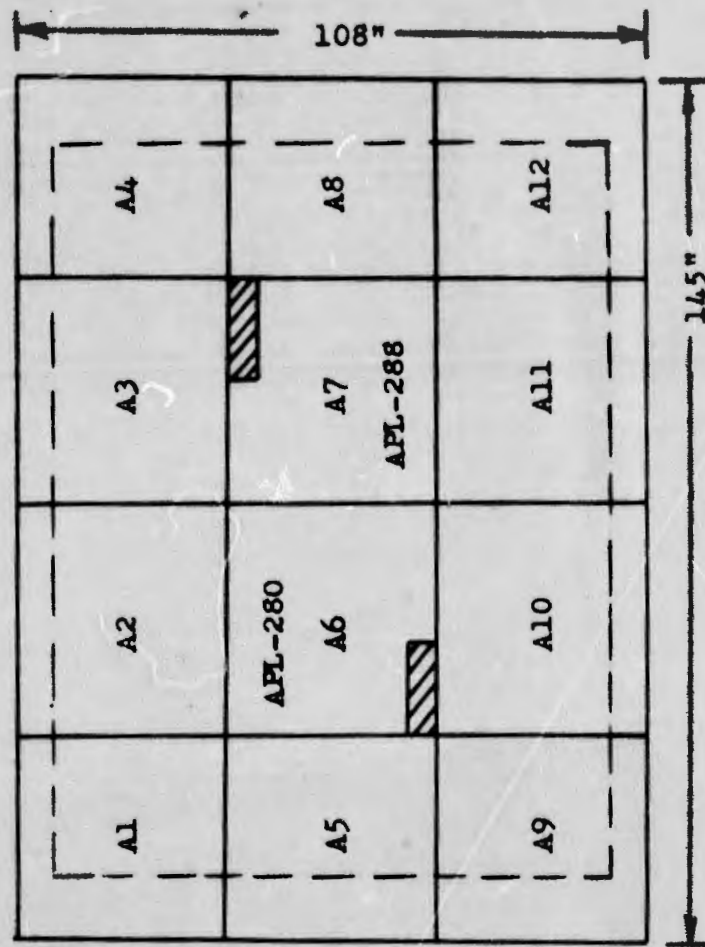


Fig. 28

-CONFIDENTIAL-

22 December 1943

UNCLASSIFIED

UNCLASSIFIED